DOCUMENT RESUME

ED 044 307 SE 010 169

AUTHOR	Mackenthun, Kenneth M.
TITLE	Nitrogen and Phosphorus in Water, An Annotated Selected Bibliography of Their Biological Effects.
INSTITUTION	Public Health Service (DHEW), Cincinnati, Ohio. Div. of Water Supply and Pollution Control.
PUB DATE	1 May 65
NOTE	140p.
AVAILABLE FROM	Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Public Health Service Pub. 1305, $0.65)
EDRS PRICE	EDRS Price MF-$0.75 HC Not Available from EDRS.
DESCRIPTORS	*Annotated Bibliographies, *Biology, Ecology, *Environment, *Pollution, *Water Pollution Control

ABSTRACT

Included in this bibliography are annotations of quantitative data on the content or concentration of nitrogen and phosphorus in plants and animals, the contribution to water of these elements from various sources (soil, fertilizers, excretion, sewage, precipitation, urban run-off), and the effect their presence has on aquatic standing crops and production rates of plankton, fish, higher aquatic plants and bottom organisms. Freshwater investigations predominate, but some marine studies are included. There is an author index and a cross-referenced table of contents to the 181 selected citations of journal articles, research reports, and books published between 1922 and 1965. Some annotations contain citations of other documents not annotated in this bibliography. (AL)

ED044307

Nitrogen and Phosphorus in Water

An Annotated Selected Bibliography of Their Biological Effects

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U.S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
Public Health Service

EDO 44307

Nitrogen and Phosphorus in Water

An Annotated Selected Bibliography of Their Biological Effects

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U.S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
Public Health Service
Division of Water Supply and Pollution Control
1965

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402 - Price 65 cents

Foreword

Now, as during no other time in history, public attention is being focused more acutely on the water enrichment problem and attendant nuisance biological growths. Because the developing megalopolis and the expanding industry are pouring nutrients into the nation's waterways at an alarming rate, algal and aquatic weed nuisances have increased in areas where before they did not exist and have magnified in areas where before their growth was tolerable. The public is demanding that remedial measures be taken to make public waters bacteriologically safe and aesthetically pleasing for multiple recreational use.

This book is written for persons faced with recognizing critical nutrient concentration values for algal development and with predicting the effects of nutrient loadings on aquatic life.

GORDON E. MCCALLUM,
Assistant Surgeon General,
Chief, Division of Water Supply and Pollution Control

Preface

For a great many years, man has been aware of the natural aging of lakes, a slow process immeasurable within the normal span of human life. Within the past quarter-century, however, the literature has documented the awareness and concern for that portion of eutrophication that is attributable to man-associated pollution. Biological nuisances including dense algal and aquatic weed growths have occurred in waters which in the past have supported only incidental populations of these plants. Plant growths in other waters have become increasingly more dense within a period of a few years. The public has become alarmed and has sought technical and sometimes legal and legislative help in rectifying local problems.

Excessive nutrients are most often blamed for the creation of plant nuisances. Among the nutrients, dominant roles have been assigned to nitrogen and phosphorus. These elements occur in natural waters, in soils, in plants and animals, and in precipitation. They are often added to water in large quantities in both domestic and industrial wastes. Wastes and fertilizers applied to land often enter watercourses and ultimately enrich those standing bodies of water whose natural physical and chemical properties encourage algal and aquatic weed development. Such growths in turn often interfere with recreation and other intended uses of water.

Investigation and research have been directed toward a solution of localized problems of accelerated eutrophication. Research and investigation will be intensified and expanded in future years. All levels of government have become vitally interested. To meet the growing needs of an expanding population, radical solutions must be found for the problem that threatens recreational and many other uses of water.

This book compiles a selected bibliography of literature with annotations specifically directed toward nitrogen and phosphorus and the ramifications of these and closely associated elements in the aquatic environment. Related intimately to the aquatic environment is the soil environment, the nutrients deposited thereon, and the atmosphere. These have not been neglected. Freshwater investigations have received preferential treatment but marine investigations and research have been considered as such may relate or furnish clues to the solution of problems in freshwater.

This book was compiled for the engineer and the scientist who are faced with predicting limnological changes resulting from nutrient loadings to standing bodies of water, with recognizing critical concentration values for algal development, and with predicting the effects of fertilizers on aquatic life. Information is given on expected contributions from various nutrient sources, aquatic standing crops and production rates, and the nitrogen and phosphorus content or concentration in plants and animals. This compilation is a beginning, not an end. It will be supplemented as additional data are amassed.

Cincinnati, Ohio
May 1, 1965

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Hayes, O. E..... 1957 (See Mackenthun et al., 1964)
Helfrich, P..... 1957 (See Odum, 1959)
Hickling, C. F..... 1948 (See Odum, 1959)

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Hoagland, D. R---------- 1944*
Hoffman, D. A---------- 1961*
Hogetsu, K---------- 1954 (See Odum, 1959)
Holden, A. V---------- 1961*
Hooper, F. F---------- 1953* (Also see Mackenthun et al., 1964), 1964*
Hughes, E. O---------- 1958 (See Fitzgerald, 1965)
Hutchinson, G. E-------- 1941 (See Benoit, 1955; Hooper and Elliott, 1953), 1957*
Ichimura, S---------- 1954 (See Odum, 1959)
Ignatieff, V---------- 1958*
Ingram, W. M---------- 1964
Jackson, M. L---------- 1957 (See Mackenthun et al., 1964)
Johannes, R. E---------- 1964a*, 1964b*, 1964c*
Jones, N. R---------- 1959
Juday, C---------- 1922, 1925, 1927*, 1931 (See Benoit, 1955), 1931*, 1934 (See Provasoli, 1963), 1940 (See Odum, 1959), 1941*
Kamen, M. D---------- 1948
Katz, W. J---------- 1954
Kazmierczak, E---------- 1964
Kemmerer, G. I---------- 1927
Ketchum, B. H---------- 1939a, 1949 (See Redfield et al., 1963) (See Harvey, 1960; Rice, 1953), 1939b (See Harvey, 1960; Rice, 1953), 1963
Kevern, N. R---------- 1965*
Knight, A---------- 1962*
Kohn, A. J---------- 1957 (See Odum, 1959)
Kortschak, H. P---------- 1957 (See Odum, 1959)
Krantz, B. A---------- 1961
Kratz, W. A---------- 1955* (Also see Krauss, 1958)
Krauss, R. W---------- 1958*
Kuenzler, E. J---------- 1961*
Kuhn, P. A---------- 1956 (See McGauhey et al., 1963)
Lackey, J. B---------- 1945, 1945* (Also see Anon., 1949), 1949* (Also see Lackey, 1958), 1958*
Lang, R---------- 1942 (See Odum, 1959)
Lea, W. L---------- 1950 (See Sawyer, 1952), 1954*
Lee, G. F---------- 1964
Lenz, R. T---------- 1945 (Also see Mackenthun et al., 1964)
Letts, E. A---------- 1908 (See Lackey, 1958)
Liebig, J---------- 1849 (See Millar, 1955)
Lindeman, R. L---------- 1941 (See Odum, 1959)
Livingstone, D. A-------- 1952

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Love, R. M	1959*
Lovern, J. A	1959
Low, J. B	1944*
Ludwig, H. F	1963, 1964*
Lueck, B. F	1956 (See Mackenthun et al., 1964)
Lueschow, L. A	1960
Lund, H. A	1948 (See Donahue, 1961)
MacFarlane, C	1952 (See Odum, 1959)
MacPherson, L. B	1958*
Mackenthun, K. M	1960,* 1961 (See Mackenthun et al., 1964), 1962,* Unpublished,* 1963, 1964*
Mackereth, F. J	1953 (See Krauss, 1958)
Malhotra, S. K	1964*
Mandal, L. N	1956 (See Krauss, 1958)
Martin, W. E	1962
Matheson, D. H	1951*
Mathews, H. M	1963
McCarter, J. A	1952
McCarter, J. R	1940 (See Walton, 1951)
McDermott, J. H	1961 (See Porges and Mackenthun, 1963)
McGauhey, P. H	1963*
McIntire, C. D	1962*
McKee, H. S	1962*
McLachlan, J	1961 (See Fitzgerald, 1965)
McNabb, C. D	1960 (See Mackenthun et al., 1964)
McVicker, M	1963*
Meloche, V. W	1941
Menzel, D. W	1962*
Metz, L. J	1954 (See Donahue, 1961)
Metzler, D. F	1958 (See Mackenthun et al., 1964)
Meyer, J	1948 (See McKee, 1962), 1959*
Mikkelsen, D. S	1962*
Millar, C. E	1955*
Miller, M. D	1962*
Miller, R. B	1961
Min, H. S	1963
Monday, C. A., Jr	1961 (See Porges and Mackenthun, 1963)
Moore, G. M	1939 (See Hooper and Elliott, 1953)
Moore, H. B	1958*
Morgan, J. J	1959, 1961, 1962
Mortimer, C. H	1941 (See Tanner, 1960)
Moyle, J. B	1940 (See Mackenthun et al., 1964), 1956*, 1961 (See Mackenthun et al., 1964)
Mulford, S. F	1954 (See Mackenthun et al., 1964)

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Müller, W---------- 1953*
Myers, J---------- 1955 (Also see Krauss, 1958)
Needham, P. R---------- 1958 (See Mackenthun et al., 1964)
Neel, J. K---------- 1961 (See Porges and Mackenthun, 1963)
Neess, J. C---------- 1949*, 1961, 1964
Negelein, E---------- 1920 (See McKee, 1962)
Neil, J. H---------- 1957
Nelson, L. B---------- 1963
Nesselson, E. J---------- 1954 (See McGauhey et al., 1963)
Odum, H. T---------- 1957 (Also see Odum, 1959) (See Knight, and Ball, 1962), 1959
Odum, E. P---------- 1957 (See Odum, 1959), 1959*
Ohle, W---------- 1953*
Olive, J. R---------- 1961
Olson, T. A---------- 1959, 1960
Oswald, W. J---------- 1962 (See McGauhey et al., 1963)
Overbeck, J---------- 1961*
Ovington, J. D---------- 1956 (See Odum, 1959), 1957 (See Odum, 1959)
Owen, R---------- 1953 (Also see McGauhey et al., 1963)
Page, H. J---------- 1958
Paloumpis, A. A---------- 1960*
Pampfer, E---------- 1959
Park, O---------- 1949 (See Moore, 1958)
Park, T---------- 1949 (See Moore, 1958)
Parker, C. D---------- 1962* (Also see McGauhey et al., 1963)
Pearsall, W. H---------- 1956 (See Odum, 1959)
Pearson, E. A---------- 1963
Peek, C. A---------- 1961
Penfound, W. T---------- 1956 (See Odum, 1959)
Peterson, W. H---------- 1925, 1926a
Phillips, R. C---------- 1959
Phinney, H. K---------- 1961*
Pintner, I. J---------- 1960
Pomeroy, L. R---------- 1963
Porges, R---------- 1963*, 1964
Pratt, D. M---------- 1950*
Prescott, G. W---------- 1960*
Provasoli, L---------- 1960*, 1961*, 1963*
Provost, M. W---------- 1958
Putnam, H. D---------- 1959*, 1960*
Rawson, D. S---------- 1952 (See Odum, 1959)
Reay, G. A---------- 1943 (See Borgstrom, 1961)
Redfield, A. C---------- 1963*

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Reid, G. W	1954
Renn, C. E	1937 (See Hooper and Elliott, 1953)
Rice, T. R	1953* (Also see Krauss, 1958)
Richards, F. A	1963, 1964
Rickett, H. W	1922* (Also see Knight and Ball, 1962), 1924* (Also see Knight and Ball, 1962)
Rigler, F. H	1956* (Also see Rigler, 1964), 1964*
Riley, G. A	1949 (See Moore, 1958), 1951 (See Ryther, 1963), 1956 (Also see Vaccaro, 1964; Also see Odum, 1959), 1957 (See Knight and Ball, 1962; Also see Odum, 1959)
Robinson, R. J	1927
Rodale, J. I	1960*
Rohde, W	1948 (See Moore, 1958)
Rohlich, G. A	1950 (See Sawyer, 1952), 1954, 1961* (See McGauhey et al., 1963), 1963, 1964
Rosenfield, A. B	1950
Rousenfell, G. A	1946 (See Odum, 1959)
Rudolfs, W	1947* (Also see Sawyer, 1952; Also see Engelbrecht and Morgan, 1959)
Ryther, J. H	1960 (See Redfield et al., 1963) 1963*, 1964
Salisbury, R. M	1950
Sanderson, W. W	1953*
Sarles, W. B	1940 (See Walton, 1951)
Sattelmacher, P. G	1962*
Saunby, T	1953*
Sawyer, C. N	1944 (See Sawyer, 1952), 1945 (Also see Anon., 1949), 1945*, 1947*, 1952*, 1954*
Schelske, C. L	1960 (See Knight and Ball, 1962)
Schmitt, K. P	1949 (See Moore, 1958)
Scott, R. H	1956 (See Mackenthun et al., 1964)
Schuette, H. A	1918*, 1928*, 1929a*, 1929b*
Shewan, J. M	1943 (See Borgstrom, 1961)
Shipman, H. R	1950
Silvey, J. K. G	1953 (See Engelbrecht and Morgan, 1959)
Sinclair, N. R	1958
Skoog, F	1950, 1952 (See Fitzgerald, 1965), 1954, 1957, 1957a
Smalley, A. E	1957 (See Odum, 1959)
Smith, E. V	1939, 1947 (See Odum, 1959)
Solimorskaja-Rodins, A. C.	1940 (See Hooper and Elliott, 1953)
Spaeth, J. P	1962
Spiegelman, S	1948

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Starrett, W. C	1960
Steel, J. H	1957 (See Knight and Ball, 1962)
Steeman, N. E	1954 (See Knight and Ball, 1962)
Stevenson, W	1949 (See Hooper and Elliott, 1953)
Stommel, H	1949 (See Moore, 1958)
Strickland, J. D. H	1960 (See Knight and Ball, 1962)
Stumm, W	1962*
Sutherland, A. K	1950
Swingle, H. S	1939*, 1947 (See Odum, 1959)
Sylvester, R. O	1961*, 1963*, 1964*
Takahashi, D	1957 (See Odum, 1959)
Tamiya, H	1957 (See Odum, 1959), (See Knight and Ball, 1962)
Tamm, C. O	1951*, 1953*
Tanimoto, T	1957 (See Odum, 1959)
Tanner, H. A	1951, 1960*
Tebo, L. B	1955 (See Mackenthun et al., 1964)
Tucker, A	1957*, 1957a*
Tucker, J. M	1961*
Vaccaro, R. F	1964*
Vallentyne, J. R	1952*
Vanderborgh, G., Jr	1949 (See Lackey, 1958)
Van Slyke, L. L	1932 (See Millar, 1955)
VanVuran, J. P. J	1948*
Verduin, J	1956 (See Odum, 1959)
Viosca, P	1935 (See Odum, 1959)
Voigt, G. K	1960*
Walton, G	1951*
Warburg, O	1920 (See McKee, 1962)
Watanabe, A	1951 and 1956 (See Krauss, 1958)
Weaver, J. E	1954 (See Odum, 1959)
Webster, G. C	1959
Weeks, O. B	1945
Weibel, S. R	1964*
Whipple, G. C	1948*
Whipple, M. C	1948
Whitford, L. A	1959*
Wielding, S	1941 (See Krauss, 1958)
Wiley, A. J	1956 (See Mackenthun et al., 1964)
Wilson, S. L	1955
Winks, W. R	1950*
Wisniewski, T. F	1956 (See Mackenthun et al., 1964)
Wolfe, M	1954 (See McKee, 1962)
Woodward, R. L	1950, 1960

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Woytinsky, E. S---------- 1953 (See Knight and Ball, 1962) (Also see Odum, 1959)
Woytinsky, W. S---------- 1953 (See Knight and Ball, 1962) (Also see Odum, 1959)
Wuhrmann, K---------- 1962 (See McGauhey et al., 1963), 1963 (See McGauhey et al., 1963)
Wurtz, A. G---------- 1962*
Zehnder, V. A---------- 1958 (See Fitzgerald, 1965)
Zicker, E. L---------- 1956*
Zilversmit, D. B---------- 1943*
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Introduction

In the press, around the conference table, and in the courts, thoughtful and extensive attention has been directed to the excessive enrichment of water, especially the standing water in recreational lakes and ponds. At no time in history except the present has the focus of public attention on the water enrichment problem been more acute, or more demanding that remedial measures be taken to make the water aesthetically pleasing for multiple recreational use. Such a public reaction results either from a greater awareness of a chronic situation that has existed over extended time or from recently produced, dynamically acute, or rapidly accelerating biological nuisances. Although it is well documented that many lakes throughout the country have been fertile reservoirs for algal development for many years, it is also equally obvious that the developing megalopolis and the expanding industry are pouring nutrients into the nation's waterways at an accelerating rate, and that aquatic weed growths and algal nuisances have increased in areas where before they did not exist and have magnified in areas where before there was a tolerable growth.

The scope of eutrophication or water enrichment is broad and the ramifications are many. In this book consideration has been limited principally to the nutrients, nitrogen and phosphorus, and to the role that these elements play in lake aging. The process of lake aging has been termed irreversible when measured by the clock of geologic time. When the refuse and rejectamenta of civilization are the principal accelerators of the process, corrective action can slow the eutrophication process, and perhaps temporarily revert it. Although they sometimes require great effort and expenditure of monies, localized nuisances may be abated. Even when nonnatural pollution may be substantially removed from a watercourse, many years may be required to effect a "flushing out" from the lake of those nutrients that have been recycling with the biomass therein. It is usually safe to assume that the lake will never again attain its crystal-clear, pristine appearance that has been so well imprinted on the minds and in the thoughts of long-time local residents. Unfortunately, in most instances, historic scientific evidence is not available with which to compare recent studies on a water body. Hopefully, as good data are amassed, this will be corrected in the future.

To properly assess a nutrient problem, consideration should be given all of those sources that may contribute nutrients to the watercourse. A partial list of these would include the nutrients in sewage, sewage effluents, industrial wastes, land drainage, applied fertilizers, precipitation, urban runoff, soils, and that which may be released from bottom sediments and from decomposing plankton. Nutrients contributed by transient ducks, falling tree leaves, and ground water may be important additions to the nutrient budget. Flow measurements are paramount in a study to quantitatively assess the respective amounts contributed by various sources during different seasons and at different flow characteristics. In the receiving lake or stream the quantity of nutrients contained by the standing crops of algae, aquatic vascular plants, fish, and other aquatic organisms are important considerations. A knowledge of those nutrients that are annually harvested through the fish catch, or that may be removed from the system through the emergence of insects will contribute to an understanding of the nutrient budget.

For comparative purposes it is valuable to know nutrient concentrations that have been found in various lakes and streams, the loadings to specific lakes under varying situations, and the retention in lakes and ponds. The interaction of specific chemical components in water, prescribed fertilizer application rates to land and to water, critical nutrient values required for algal blooms, vitamins required, other limiting factors, and the intercellular nitrogen and phosphorus concentrations are likewise important. Usually, it is necessary to determine that portion of the nutritive imput attributable to man-made or man-induced pollution that may be corrected as opposed to that imput that is natural in origin and, therefore, usually not correctable. A nutrient budget is used to determine the annual imput to a system, the annual outflow, and that which is retained within the water mass to recycle with the biomass or become combined with the solidified bottom sediments. Calculations can be made to determine those nutrient portions that are incorporated in the standing crops of the respective biomass components within the system. Calculations can also be made to determine the quantity of those nutrients that are in solution within respective vertical strata of the system and to predict those nutrient concentrations that will be immediately available for plant growth during the critical spring season. Retention time or "flush-out"time may also be calculated.

In this publication, recorded data have been presented on these and associated topics. A few of these data have been tabulated in the accompanying table. More could be added but the subject index presents an almost equally convenient method of comparing data and has the added advantage of keeping it more meaningful and within the context of the abstract.

Nutrient Population Equivalents

(From Mackenthun et al., 1964)

Nutrient source	Basic reference	Contribution		Population equivalent (PE per year)	
		N	P	N	P
Treated domestic contribution in sewage	Bush and Mulford, 1954 / Metzler et al., 1958	6–12* (9 lb/yr) / 6**lb/yr	2–4 (3 lb/yr) / 2.25 lb/yr	1	1.
Domestic duck	Sanderson, 1953	2.1 lb/yr	0.9 lb/yr	0.23 to 0.35	0.3.
Wild duck	Paloumpis and Starrett, 1960	1.0 lb/yr	0.45 lb/yr	0.11 to 0.17	0.15.
Runoff—20 percent slope, corn	Eck et al., 1957	38 lb/A/yr	1.8 lb/A/yr	4.2 to 6.3/A	0.6/A.
Runoff—8 percent slope, corn	Eck et al., 1957	18 lb/A/yr	0.5 lb/A/yr	2.1 to 3.0/A	0.166/A.
Surface irrigation diversified farming	Sylvester, 1961	2.5–24.0 lb/A/yr	0.9–3.9 lb/A/yr	0.27 to 4.0/A	0.3 to 1.3/A.
Rainwater	Hutchinson, 1957	5.5 lb/A		0.6 to 0.9/A	
Killed algae (summer maximum)	Birge and Juday, 1922	15 lb/A	1.5 lb/A	1.7 to 2.5/A	0.5/A.
Killed submerged plants	Rickett, 1922	32 lb/A	3.2 lb/A	3.6 to 5.3/A	1.1/A.
Killed fish	Beard, 1926	50 lb/ton	4 lb/ton	5.6 to 8.3/ton	1.3/ton.

* Normal range of domestic sewage for 15 California communities was given as 20 to 40 mg/l N and PO_4.

** This concentration in treated water was subtracted from the concentration in sewage to obtain domestic contribution.

If it is assumed that phosphorus is the key element in lake enrichment and that 0.015 mg/1 soluble phosphorus at the beginning of the active growing season will produce subsequent nuisance algal blooms, then dilution becomes a prime factor of consideration. Assume, then, that a treated domestic waste with a soluble phosphorus concentration of 8.0 mg/1–P is discharged to a stream with a soluble phosphorus concentration of 0.006 mg/1 soluble P. Since a lake is ultimately influenced by the nutrient concentrations in its inflowing waters, the 8.0 mg/1–P waste must receive greater than a 888:1 dilution with 0.006 mg/1–P water to be below the critical algal growth value.

Considered another way, the inorganic nitrogen ($NH_3-N+NO_2-N+NO_3-N$) and soluble phosphorus concentration occurring during the period of early spring growth that are believed to cause algal nuisances are 0.8 and 0.04 pound, respectively, per acre-foot of lake water. Thus, assuming a mean water depth of 15 feet, 12 pounds per acre of inorganic nitrogen and 0.6 pound per acre of soluble phosphorus available for organism utilization in early spring might be expected to stimulate troublesome nuisances. The treated domestic contribution in sewage lies between 2 to 3 pounds per capita per year. Assuming further that the soluble phosphorus within the water body could be calculated at 0.006 mg/1–P, the amount within 15 acre-feet of water would be 0.24 pound. With this amount present, the per capita contribution would be theoretically sufficient to fertilize 7 acres of water to a depth of 15 feet sufficient to produce algal nuisances. It becomes imperative that quantities of nutrients, however small, must be kept from natural watercourses.

From the standpoint of nutrient removal, harvesting the aquatic crops annually would be advantageous. The economics of present methods of harvesting and the scope of the problem, however, necessitate a critical appraisal of the benefits versus the costs. The expected standing crop of algae approaches 2 tons per acre (wet weight). Such would contain only about 15 pounds of nitrogen and 1.5 pounds of phosphorus. Submerged aquatic plants would be expected to approach at least 7 tons per acre (wet weight) and contain 32 pounds of nitrogen and 3.2 pounds of phosphorus per acre. Values may be higher under severe nuisance conditions.

Bottom-dwelling bloodworms (midge larvae) might be expected to occur in population densities of 300 pounds per acre (wet weight). If 6 percent of this population is annually lost as emerged insects outside the lake basin, this removes only ¼ pound per acre of nitrogen and possibly $\frac{1}{10}$ as much phosphorus.

The nitrogen content of fish flesh is approximately 2.5 percent (wet weight) and the phosphorus content 0.2 percent. Thus, to remove 40 pounds of fish would remove 1 pound of nitrogen, but 500 pounds of fish must be removed to harvest 1 pound of phosphorus.

Phosphorus occurs in rocks and soils primarily as calcium phosphate, $Ca_3(PO_4)_2$. Since the phosphate rock is sparingly soluble, leaching brings into solution small amounts of the phosphorus. In natural waters the element exists as secondary calcium phosphate, $CaHPO_4$, its form being determined by the pH of the water. The low concentration of phosphorus available from geologic sources is further reduced by biological systems, since the element is necessary for all life processes. Thus in waters remote from human influence, phosphorus exists in very low concentrations as the secondary phosphate ion and as organic phosphorus incorporated into biomass. Seasonal changes in plant and animal production result in cyclic utilization and release of phosphorus to the water.

The discharge of domestic sewage increases the concentration of phosphorus markedly. Organic phosphorus in the sewage and simple and complex phosphates from synthetic detergents are the principal contributions. Decomposition of the organic material, along with soluble phosphates, results in phosphorus concentrations far above the requirements for plant growth. Therefore, in most polluted waters, soluble phosphorus is abundant. This readily available form often furnishes a food supply for nuisance biological growths.

Nitrogen comes into solution in water as the result of nitrogen fixation from the air, ammonia from rain-out, organic nitrogen from decomposing plants and animals, and land drainage. In water solution the element exists as organic nitrogen, ammonium ion, nitrite ion, and nitrate ion. In the familiar nitrogen cycle, the proteinaceous material is decomposed by bacterial action, resulting in the inorganic ions, which are in turn incorporated into new cell material. The relative concentrations of the various forms of nitrogen depend upon the biological systems involved, as influenced by environmental conditions.

When untreated domestic sewage is discharged to a watercourse, organic nitrogen (proteins) and ammonia are the principal nitrogen constituents. In the water, nitrifying organisms decompose the organic materials and oxidize the ammonia to nitrite and nitrate. Since the nitrite ion is a transient form it is usually present in very low concentrations.

Treated sewage has undergone partial oxidation in the treatment process. Therefore the nitrite and nitrate forms are increased in well treated sewage, while the organic nitrogen and ammonia are reduced.

The discharge of human wastes results in an abundance of nitrogen in all forms, causing an abrupt change in the nutrient balance of the stream.

Definitions and Equivalents

cfs=cubic feet per second; cfs×448.8=gallons per minute; cfs ×5.4×10⁶=pounds per day

g/l=grams per liter; g/l×1,000=parts per million

g/m^2=grams per square meter; g/m^2×8.922=pounds per acre

ha=hectare; ha×2.471=acres

kg=kilograms; kg×2.2=pounds

kg/ha=kilograms per hectare; kg/ha×0.8922=pounds per acre

metric tons×2,204=pounds

μg-at P/g=microgram atoms phosphorus per gram=31 parts per million phosphorus

μg-at P/l=microgram atoms phosphorus per liter=31 parts per billion phosphorus

μg/g=micrograms per gram=ppm

μg/l=micrograms per liter=ppb; μg/l×10^{-3}=parts per million

$\mu g/m^2$=micrograms per square meter; $\mu g/m^2 \times 8.92 \times 10^{-6}$=pounds per acre

mg/g=milligrams per gram; mg/g×10^3=ppm

micromoles P per 100 grams×0.31=parts per million

mg/l=milligrams per liter=parts per million

mg/m^3=milligrams per cubic meter; mg/m^3×0.00272=pounds per acre-foot

mg/m^2=milligrams per square meter; mg/m^2×8,922=pounds per acre

mg %=milligrams percent=milligrams in 100 grams=1 part in 100,000 parts wet weight; mg %×0.1=ppm

mgd=million gallons per day; mgd×1.547=cubic feet per second

ppb=parts per billion

ppm=parts per million

P_2O_5=phosphorus pentoxide; P_2O_5×0.436=P

PO_4=phosphate; PO_4×0.326=P

NO_3=nitrate; NO_3×0.226=N

Parts per million×cubic feet per second×5.4=pounds per day (gallons per minute×2.228×10^{-3}=cubic feet per second)

Parts per million×8.34×gallons per day×10^{-6}=pounds per day (gallons per minute×1,440=gallons per day)

As a handy reference, these definitions and equivalents are presented in a fold-out sheet at the back of this book.

Abbott, W. 1957.
Unusual Phosphorus Source for Plankton Algae. Ecology, Vol. 38, pp. 152; Water Pollution Abstracts, Vol. 30, No. 8, Abs. No. 1248.

Tests were made to find the source of phosphorus used by planktonic algae in Lake Houston, a new impounding reservoir in Texas. Chemical analyses of plankton and noncolloidal detritus from the lake were made, but no phosphorus was detected in these samples. It was observed that run-off from the watershed following rains produced a high load of colloidal clay particles in the water. Samples were taken, half of which were filtered and half still contained collodial material before being analyzed for phosphorus. Samples containing colloidal matter contained an average of 85 micrograms per liter of phosphorus in the phosphate equivalent form while the filtered samples contained only minute quantities. It was, therefore, deduced that the planktonic algae were deriving their nutritive phosphorus from complex polyphosphates or organic phosphorus compounds without the aid of dissolved phosphate equivalent intermediate stage.

Allen, M. B. 1955.
General Features of Algae Growth in Sewage Oxidation Ponds. California State Water Pollution Control Board, Sacramento, California, Publication No. 13, pp. 11–34.

The maximum yield of algae obtainable from domestic sewage in the laboratory was 1 to 2 grams dry weight per liter of sewage. The element most severely limiting algal growth in the sewages studied was nitrogen. To obtain any appreciable increase in algal production it was necessary to supplement the sewage with nitrogen as well as with carbon. The mass of algae present was determined by centrifuging the cells from a known volume of medium, transferring to a tared crucible, drying, and weighing.

Algal crops in the field are more difficult to evaluate because of uncertainty as to whether all the suspended solids should be considered as algal cells, but 0.5 gram dry weight per liter appears to be the maximum observed. *Chlorella* and *Scenedesmus* were the photosynthetic organisms most important in the functioning of the oxidation ponds. It was found that these algae did not grow on sewage in the dark and that they did not reduce the content of oxidizable mat-

ter in sewage when growing on it in the light. Their development in the oxidation ponds is thus possible only by photosynthesis, for which they use carbon dioxide produced in the oxidation of organic matter by colorless organisms.

Anderson, G. C. 1961.
Recent Changes in the Trophic Nature of Lake Washington—A Review. Algae and Metropolitan Wastes, U.S. Public Health Service, SEC TR W61–3, pp. 27–33.

Lake Washington near Seattle, Washington, a lake of 21,641 acres with a maximum depth of 214 feet, receives the treated sewage of 76,300 people; eutrophication has resulted. In 1955, ". . . for the first time, there appeared an increased growth of phytoplankton made up mainly by the blue-green alga *Oscillatoria rubescens*, a notorious indicator of pollution in many lakes." The nitrogen (N) loading on the lake was 280 pounds per acre per year in 1957; the phosphorus (P) loading was 12 pounds per acre per year. The hypolimnetic oxygen deficit has increased from 105 pounds per acre per month in 1933 to 279 pounds per acre per month in 1955. The maximum hypolimnetic concentration of phosphate (PO_4-P) reached in the deepest waters was 23 ppb in 1950, 89 ppb in 1957, and 74 ppb in 1958. The standing crop of phytoplankton as indicated by measurements of phytoplankton volume and chlorophyll measurements was 0.6 part per million by volume in 1950, 1.6 in 1955, and 4.2 in 1956.

Andrews, W. B. 1947.
The Response of Crops and Soils to Fertilizers and Manures. W. B. Andrews, State College, Mississippi, 459 pp.

In North Carolina, when adequate phosphorus and potash were used, 20 pounds of nitrogen per acre produced 32 bushels of corn, 60 pounds of nitrogen per acre produced 59 bushels, and 120 pounds of nitrogen per acre produced 72 bushels.

In the process of becoming soluble, nitrogen is converted into nitric acid which combines with important elements in the soil, such as calcium and potassium, among other elements, to form soluble compounds which are subject to leaching, thus causing the loss of these mineral elements as well as nitrogen. In Kentucky, the pounds of nitrogen leached per acre ranged from 0 to 10 for alfalfa, and 0.3 to 12.2 for bluegrass to 29 to 165 where no crop was grown.

The fertilizing elements removed in harvested crops were given as follows:

Crop	Part of crop	Yield per acre	Pounds of nirtogen	Pounds of phosphoric acid (P_2O_5)
Alfalfa	Hay	4,000 lbs	93	25
Corn	Grain	25 bu	24	14
	Stover	1,667 lbs	16	5
Cotton	Lint	200 lbs		
	Seed	360 lbs	14	6
	Stalks	600 lbs	10	3
Potatoes	Potato	200 bu	43	17
	Tops		40	7
Soybeans	Hay	2,000 lbs	50	12
	Seed	15 bu	66	16
Tobacco	Leaves	1,000 lbs	37	7
	Stalks	800 lbs	17	7

Soils that have a high amount of nitrogen before being brought into cultivation maintain a higher nitrogen content under cultivation than do soils which have a low amount of nitrogen before being brought into cultivation. The average nitrogen content in soil organic matter in the surface 7 inches of 8 different soil types was 4,276 pounds per acre for virgin soil and 2,781 pounds per acre for cultivated soil for a 35 percent loss in nitrogen through cultivation. Continuous cropping of corn depleted the total nitrogen in the upper 7 inches of soil by 52 percent in the first 25 years and 5 percent in the second 25 years.

In the Southeast, 48 pounds of phosphate is generally recommended each year for continuous cotton production. Fertile soils may contain as much as 5,000 to 10,000 pounds of phosphate per acre to a depth of 6⅔ inches; however, most soils contain considerably less than 5,000 pounds. Most of the phosphorus in the soil is in a form which is not available to plants, and the rate at which phosphorus becomes available is too slow to supply the needs of crops on most soils.

The pounds of nitrogen, phosphate, and potash in 1 ton of manure was given as follows:

Animal	Pounds dry matter	Nitrogen	Phosphate	Potash
Cattle:				
Solid	322	6.4	4.2	3.2
Liquid	124	19.0	.6	19.0
Hens, solid	900	20.0	16.0	8.0
Hogs:				
Solid	360	12.0	9.2	8.8
Liquid	66	6.0	2.4	20.0
Horses:				
Solid	486	10.0	6.0	4.8
Liquid	198	24.0	Trace	30.0
Sheep:				
Solid	690	13.0	9.2	4.6
Liquid	256	33.6	.6	42.0

Normally 500 to 600 pounds of fish per acre are produced in well fertilized ponds and 100 to 200 pounds in unfertilized ponds in Ala-

bama. The fertilizers recommended for fishing ponds by the Alabama Agricultural Experiment Station per acre of water were as follows:

40 pounds of sulfate of ammonia
60 pounds of superphosphate (16%)
5 pounds of muriate of potash
15 pounds of lime.
or
100 pounds of neutral 6–8–4
10 pounds of nitrate of soda.

Two to three fertilizer applications should be made at weekly intervals of four weeks thereafter until October. When the water becomes clear enough for the bottom of the pond to be seen through 1½ to 2 feet of water, fertilizer is needed.

Anon. 1949.
Report on Lake Mendota Studies Concerning Conditions Contributing to Occurrence of Aquatic Nuisances 1945–1947. Wisconsin Committee on Water Pollution, Madison, Wisconsin, 19 pp. (Mimeo.)

The soluble phosphorus contributions to Lake Mendota, Wisconsin, from September 1945, through August 1946, was 4,198 pounds corresponding to 0.43 pound per acre as P. The following year the contribution was 7,137 pounds or 0.76 pound per acre. Soluble phosphorus averaged 0.048 mg/l for all streams entering the lake.

The inorganic nitrogen entering Lake Mendota was 203,609 pounds corresponding to 20.8 pounds per lake acre as N. The contribution of 185,472 pounds during the second year was equivalent to 19.0 pounds per acre.

During the survey, the arbitrary definition of 500 organisms of a given species per ml as constituting an algal bloom was used with the modification that those organisms were included whose population was less than 500 but whose volume was 10,000 volumetric standard units or more. The fertilization-bloom relationship using additional data from Lackey and Sawyer (1945) was given as follows:

Lake	Inorganic nitrogen (pounds per acre per year)	Inorganic phosphorus (pounds per acre per year)	Number of algal blooms per year
Mendota	19.9	0.59	10
Monona	81	7.5	43
Waubesa	435	62.8	56
Kegonsa	162	35.9	40

Since the concentration of inorganic nitrogen in Lake Mendota varied between 0.15 and 0.58 mg/1 (N) from 1945 to 1947, and inorganic phosphorus varied from 0.008 to 0.082 mg/1 (P), it may be

concluded that a drainage area that is nonurban, such as that of Lake Mendota, can supply by runoff through its drainage system sufficient nutrients to fertilize the water to the nuisance-producing level.

Lackey, J. B. and C. N. Sawyer. 1945. Plankton Productivity of certain Southeastern Wisconsin Lakes as related to Fertilization. Sewage Works Journal, Vol. 17, pp. 573–585.

Anon. 1950.
Water Supply. Progress Report of the Committee on Water Supply of the American Public Health Association. American Journal of Public Health, Vol. 40, No. 5, pp. 110–120; Water Pollution Abstracts, Vol. 23, No. 8, Abs. No. 902.

The majority of cases of methemoglobinemia are associated with water containing at least 60 mg/l nitrate nitrogen, but some rural supplies contain up to 500 mg/l without the disease occurring.

Anon. 1964.
"Breakthrough" in Poultry Manure. Compost Science, Vol. 5, No. 2, p. 30.

A British firm, Hydraulics Developments Ltd., is reported to have developed a process of drying poultry manure droppings and producing a dry sterile powder for use as a natural organic fertilizer. Ministry of Agriculture analyses of 10 samples gave an average reading of 5.3 percent nitrogen, 5.1 percent phosphate, and 2.1 percent potash.

Anon. 1964a.
Midwest Farm Handbook. The Iowa University Press, Ames, Iowa, 474 pp.

Recommendations for continuous fertilizer application to corn in the midwestern States are about 80 to 100 pounds of nitrogen per acre and 40 to 60 pounds of phosphate (P_2O_5) per acre; and to small grains, about 20 to 50 pounds of nitrogen per acre and 40 to 60 pounds of phosphate (P_2O_5) per acre. Some variation in the recommendations existed because of different soil types given consideration.

Anon. 1964b.
Activities Report, July 1, 1963–June 30, 1964. Basic and Applied Sciences Branch, Division of Water Supply and Pollution Control, Public Health Service, 57 pp.

A year's measurements of storm runoff water quality and quantity from a 27-acre residential-commercial urban area indicated annual

amounts of PO_4 and total N to be 9 and 11 percent, respectively, of the estimated raw sewage content from sources on the area.

At Coshocton, Ohio, two storms with 2.21 to 5.09 inches of rainfall per storm produced a runoff of 6,600 to 76,300 gallons per acre; phosphate (PO_4) in the runoff water ranged from 0.05 to 0.42 pound per acre, and total nitrogen (N) ranged from 0.20 to 6.12 pounds per acre.

Ball, R. C. 1949.
Experimental Use of Fertilizer in the Production of Fish-Food Organisms and Fish. Michigan State College Agricultural Experiment Station Technical Bulletin No. 210, pp. 1–28.

Twenty-one ponds at three Michigan fish hatcheries were utilized in the summer of 1946 for experimental work to determine the value of fertilizers in the production of fish. Organic fertilizer in the form of barnyard manure was applied early in the spring at the rate of 1 ton to each 1½ acres of water surface. During the summer, inorganic fertilizer (10–6–4) was applied at a rate of 33.3 pounds per acre per week. The general indication was that there was a greater production of fish in fertilized water. The production of invertebrate organisms, as determined by dredge sampling, was 42 percent greater in the fertilized ponds than in the nonfertilized ponds, and the production of plankton organisms was 3.3 times greater.

Ball, R. C. 1950.
Fertilization of Natural Lakes in Michigan. Transactions American Fisheries Society, Vol. 78 (1948), pp. 145–155.

Inorganic fertilizer (10–6–4) was applied to two state-owned lakes in northern Michigan, one a 4.3-acre trout lake and the other a 27.5-acre warm-water lake. Two nearby lakes were kept under observation as controls. Fertilization was carried out at a rate of about 100 pounds per acre from June until September, 1946, and from May until August 20, 1947. Fertilizer brought about a plankton-algae bloom the first summer in the warm-water lake and produced a heavy growth of filamentous algae the second summer. No appreciable oxygen depletion occurred during the winter following the first season of fertilization. Chemical analysis in February of the second winter showed severe oxygen depletion, with oxygen levels at less than 1 mg/l at all depths. An almost complete winterkill occurred in both fertilized lakes. No winterkill occurred in the control lakes.

Ball, R. C. and H. A. Tanner. 1951.
The Biological Effects of Fertilizer on a Warm-Water Lake. Michigan State College, Agricultural Experiment Station, Tech. Bull. 223, pp. 1–32.

Inorganic fertilizer (10–6–4) was applied in the shoal areas of North Twin Lake, which comprises 27.5 acres, at a rate of 100 pounds every 3 weeks from early May until mid-September of 1946 and 1947. A definite increase in plankton followed each application of fertilizer. Heavy mats of filamentous algae appeared during the second summer and were a nuisance to fishermen, overburdened higher aquatic plants, and had an unpleasant odor as they decayed. A statistical analysis of growth rates before and during fertilization showed a highly significant increase in growth following fertilization for all major game fishes and for all ages for which data were available. An almost complete winter-kill of fish followed the second summer of fertilization.

Beard, H. R. 1926.
Nutritive Value of Fish and Shellfish. Report U.S. Commissioner of Fisheries for 1925, pp. 501–552.

The approximate nitrogen content of fish flesh is 2.5 percent (wet weight) and the phosphorus content 0.2 percent. Thus it would be necessary to harvest about 1 ton of fish to remove 50 pounds of nitrogen and 4 pounds of phosphorus; 40 pounds of fish would remove 1 pound of nitrogen and 500 pounds of fish would remove 1 pound of phosphorus.

Bennett, G. W. 1962.
Management of Artificial Lakes and Ponds. Reinhold Publishing Corporation, New York, 283 pp.

The fertilization of ponds and lakes cannot be recommended as a general fish management technique outside of the southeastern United States, because the results are too variable and uncertain. Once the fertility of small impoundments in productive soils has been built up, this fertility may manifest itself in luxuriant annual crops of filamentous algae, blue-green algae, or rooted aquatic vegetation. There are already numerous examples of such ponds, most of which are quite productive of fish; but they are problem waters because a treatment to kill rooted vegetation will be followed by obnoxious blooms of algae which in turn may require chemical treatment. These lakes have reduced aesthetic values, and fishing and swimming are limited by plant growths of one type or another. In ponds in some of the

least productive soil types in Illinois the addition of recommended amounts of inorganic fertilizer increased the average standing crop of fish by only about 1.22 times. The improvement in fishing was such that uninformed fishermen could not tell which ponds were fertilized and which were not; yet in terms of total yield, rate of catch, and average size, the fertilized ponds produced considerably better bluegill fishing than did unfertilized control ponds. In contrast, the controls usually produced a higher yield of bass, 10 inches or larger, than did the fertilized ponds.

Benoit, R. J. 1955.
Relation of Phosphorus Content to Algae Blooms. Sewage and Industrial Wastes, Vol. 27, No. 11, pp. 1267–1269.

The author cites Juday and Birge (1931) as reporting a mean of 23 parts per billion total phosphorus for 479 lakes of northeastern Wisconsin, and Hutchinson (1941) as reporting a mean of 21 parts per billion total phosphorus for 23 analyses of the surface water of Linsley Pond, North Branford, Connecticut.

An attempt is made to answer questions regarding the type of phosphorus for which to analyze by a definition of terms. Total phosphorus is determined by digesting an unfiltered sample and determining the phosphate content by the molybdate method. If a filtered sample is digested, and the sample analyzed for phosphate, the total soluble phosphate is determined. The difference between total phosphate and total soluble phosphate is termed particulate phosphate. This form is not immediately suitable for algal metabolism, although all phosphate is potentially available when released into solution by the activity of bacteria.

Juday, C. and E. A. Birge. 1931. A Second Report on the Phosphorus Content of Wisconsin Lake Waters. Transactions Wisconsin Academy Sci., Arts, Letters, Vol. 26, pp. 353–382.

Hutchinson, G. E. 1941. Limnological Studies in Connecticut: IV Mechanism of Intermediary Metabolism in Stratified Lakes. Ecological Monographs, Vol. 11, pp. 21.

Benoit, R. J. and J. J. Curry. 1961.
Algae Blooms in Lake Zoar, Connecticut. Algae and Metropolitan Wastes, U.S. Public Health Service, SEC TR W61–3, pp. 18–22.

Lake Zoar was formed in 1919 by Stevenson Dam on the Housatonic River and by 1947 algae were so plentiful that a serious nuisance was created for lake-side property owners. The lake volume is estimated to be 42,800 acre-feet and the average flow of the Housatonic River at

Lake Zoar is 2,500 cfs, indicating a flow through time of 9 days. During the algal season, low monthly flows result in a replacement of the lake volume every 40 days. About 183 pounds per day of phosphorus (P) enter Lake Zoar giving rise to a concentration of 12 to 41 parts per billion in the water mass.

Birge, E. A. and C. Juday. 1922.
The Inland Lakes of Wisconsin. The Plankton. I. Its Quantity and Chemical Composition. Wisconsin Geological and Natural History Survey, Bulletin No. 64, Scientific Series No. 13, pp. 1–222.

Computations based on the area and total volume of Lake Mendota, Wisconsin, show that the largest standing crop of spring plankton yielded 360 pounds while the largest autumn crop was 324 pounds per acre. The smallest summer minimum amounted to 124 pounds per acre and the smallest winter minimum, 98 pounds per acre. The average amount of organic matter yielded by the entire series of plankton catches from Lake Mendota was 214 pounds per acre. These figures represent the weight of the dry organic matter in the plankton; the wet weight would be approximately ten times as large. In 166 analyses over a 7-year period, the minimum mean annual percentage of total nitrogen (N) varied from 3.92 to 6.60 percent (dry weight) and the maximum mean annual percentage ranged from 7.02 to 9.97 percent.

The percentages of total nitrogen (N) and phosphorus (P) on a dry weight basis are presented for a number of organisms:

Organism	Percentage of the dry weight	
	N	P
Microcystis	9. 27	0. 52
Anabaena	8. 27	. 53
Volvox	7. 61	1. 10
Cladophora	2. 77	. 14
Myriophyllum	3. 23	. 52
Cyclops	9. 57	1. 02
Limnocalanus	7. 18	. 78
Daphnia pulex	6. 55	1. 60
Daphnia pulex	8. 61	1. 54
Daphnia pulex	7. 55	1. 48
Leptodora	9. 28	1. 56
Cambarus	6. 60	1. 16
Hyalella	7. 37	1. 20
Hirudinea	11. 13	. 76
Zygoptera	10. 62	. 66
Sialis	8. 07	. 64
Chironomus tentans	7. 36	. 93

Borgstrom, G. (Editor), 1961.
Fish as Food. Academic Press, New York. 725 pp.

In fish cultivation, 30 to 50 kg. of pure phosphoric acid per hectare of water surface leads to a yield increase of about 100 kg. of fish flesh per hectare. On the basis of numerous experiments, it may be expected that 1 kg. of phosphoric acid will render an additional yield of 2.1 kg. of fish flesh.

In general, the protein content is calculated by multiplying the amount of nitrogen with the coefficient 6.25 although there is disagreement on the specific coefficient. Protein nitrogen is by far the most important nitrogen fraction. The distribution of nitrogen in fish flesh was given as follows:

Species	Total N (%)	Protein N (%)	Reference
Cod, Atlantic	2.83	2.47	Reay et al. (1943).
Herring, Atlantic	2.90	2.53	Boury (1936).
Sardine	3.46	2.97	Boury (1936).
Haddock	2.85	2.47	Reay et al. (1943).
Lobster	2.72	2.04	Campbell (1935).

The reported acid-soluble total phosphorus of the fish muscle ranged from 5,670 to 15,300 micromoles per 100 grams (approximately 1,814 to 4,896 parts per million wet weight or 0.18 to 0.49 percent; 200 to 600 pounds of fish would contain 1 pound of phosphorus).

Boury, M., 1936. Recherches sur l'alteration du poisson. Rev. trav. office pêches maritimes, Vol. 9, pp 401–419.

Campbell, J., 1935. The non-protein nitrogenous constituents of fish and lobster muscle. J. Biol. Board Can., Vol. 1, pp 179–189.

Reay, G. A., C. L. Cutting, and J. M. Shewan, 1943. The Nation's Food. VI. Fish as Food. II. The Chemical Composition of Fish. J. Soc. Chem. Ind., Vol. 62, pp 77–85.

Bosch, H. M.; A. B. Rosenfield; H. R. Shipman, and F. L. Woodward. 1950.
Methemoglobinemia and Minnesota Well Supplies. Journal American Water Works Association, Vol. 42, pp. 161–170; Water Pollution Abstracts, Vol. 23, No. 11, Abs. No. 1283.

Because 139 cases of cyanosis of infants had occurred in Minnesota since 1947 an investigation was made of well water supplies throughout the state. Of the 125 dug wells and 4 drilled wells examined as having been directly concerned in cases of the illness, none contained less than 10 mg/l nitrate nitrogen (NO_3-N) and only 2 contained as little as 10 to 20 mg/l. The average concentration of nitrate nitrogen (NO_3-N) in all the wells suspected of being responsible for the devel-

opment of methemoglobinemia was 102 mg/l. None of the wells reached the standards for safe water supplies specified by the Minnesota Department of Health. Five hundred and fourteen municipal supplies were examined throughout the state; of these 5.4 percent contained over 5 mg/l nitrate nitrogen, 3.1 percent contained 10 mg/l or more, and the highest concentration determined was 27 mg/l found in a dug well in a section of the state from which most of the cases of methemoglobinemia had been reported.

Burkholder, P. 1929.
Biological Significance of the Chemical Analyses. *In:* Preliminary Report on the Cooperative Survey of Lake Erie, Season of 1928. Bulletin Buffalo Society of Natural Science, Vol. 14, No. 3, pp. 56–72. [From Putnam and Olson, 1959]

Greatest concentration of ammonia was found at the surface of Lake Erie in September (0.038 mg/l). At the bottom depth of 17 meters, there was 0.08 mg/l. Average for all stations showed a marked increase in ammonia content of the upper strata as the season advanced; in July it was 0.014 mg/l, in August, 0.015 mg/l, in September, 0.03 mg/l. Nitrates were more abundant than other forms of nitrogen. The greatest amount was found at intermediate depths in July when the value reached 0.20 mg/l. An average for all stations was 0.15 mg/l in July, 0.123 mg/l in August, and 0.137 mg/l in September.

Burkholder, P. R. and L. M. Burkholder. 1956.
Vitamin B_{12} in Suspended Solids and Marsh Muds Collected Along the Coast of Georgia. Limnology and Oceanography, Vol. 1, No. 3, pp. 202–208.

The vitamin B_{12} content of suspended solids in river and sea waters and in marsh muds, collected along the coast of Georgia, was determined by means of the *E. coli* mutant assay. Appreciable amounts of vitamin B_{12} are carried on suspended particles of river water, the brown water types showing highest concentrations, up to 6.4 μg per gram of solids. Vitamin B_{12} content of particulate matter in the sea waters varied over the range 0.0027 to 0.130 μg per liter. Calculated in relation to dried solids, the highest concentration of B_{12} was 0.736 μg per gram of solids. It was concluded that suspended particles are important in the vitamin nutrition of the sea and that bacteria are significant producers and carriers of vitamin B_{12} in the marine environment.

Campbell, W. A. B. 1952.
Methemoglobinemia due to Nitrates in Well Water. British Medical Journal, Vol. 2, pp. 371–373.

Cases of infantile nitrate poisoning have been reported to arise from concentrations ranging from 15 to 250 mg/l nitrate nitrogen (NO_3-N).

Chalupa, J. 1960.
Eutrophication of Reservoirs by Atmospheric Phosphorus. Sci. Pap. Inst. Chem. Technol., Prague, Fac. Technol. Fuel. Wat., Vol. 4, Pt. 1, pp 293–308 (English summary); Water Pollution Abstracts, Vol. 35, No. 5, Abs. No. 660.

Data collected over a 7-month period in 1958–59 at the Sedlice Reservoir, Czechoslovakia, show that the whole reservoir (35.8 ha) received about ¾ kg. of inorganic phosphorus (as P_2O_5) from the atmosphere. This source of phosphorus is important in stimulating primary production of organisms in the trophogenic zone during periods of normal thermal stratification when the penetration of inorganic phosphorus from the bottom layers cannot satisfy the demand of developing organisms in the surface layers.

Chandler, D. C. and O. B. Weeks. 1945.
Limnological Studies of Western Lake Erie. V. Relation of Limnological and Meteorological Conditions to the Production of Phytoplankton in 1942. Ecological Monographs, Vol. 15, pp. 436–456. [From Putnam and Olson, 1959]

All analyses were made on composite samples prepared from surface samples and from samples at 5 and 9 meter depths. All analyses were completed within 6 hours of the time of collection.

Organic nitrogen varied from a high of 26 micrograms per liter on August 26 to a low of 2 micrograms per liter on September 18; these extremes coincided with a high and low level of phytoplankton, respectively.

Soluble phosphate phosphorus values varied from 1 to 8 micrograms per liter with the high point occurring at three times: (1) at the time of greatest organic phosphorus concentration, (2) during a period of increased turbidity which apparently resulted from increased river discharge, and (3) two weeks following the cessation of the autumn phytoplankton pulse. Lowest values occurred when the phytoplankton population was decreasing. Twenty-nine percent of the total phosphorus content was in the soluble phosphate phosphorus state.

Nitrate nitrogen varied from 0 to 1,400 micrograms per liter, ammonia nitrogen from 8 to 120 micrograms per liter, and nitrite nitrogen from 0 to 38 micrograms per liter.

Chu, S. P. 1942.
The Influence of the Mineral Composition of the Medium on the Growth of Planktonic Algae. Part I. Methods and Culture Media. Journal of Ecology, Vol. 30, No. 2, pp. 284–325.

With few exceptions the planktonic algae investigated grow equally well in media supplied with nitrate and in those supplied with ammonium salts as long as the N concentration is within the optimum range, but in lower N concentrations growth is generally better when nitrate is supplied. The requirements of N and P agree well among the different planktonic algae, although there are minor differences in the upper and lower limits that are suitable. All of the algae studied flourished in media with N ranging from 1 to 7 and P from 0.1 to 2 mg/l respectively. The algae are likely to suffer from a deficiency when the concentration of N is below 0.2 mg/l and that of P below 0.05 mg/l and from an inhibiting effect when the concentration of N and P exceed 20 mg/l. The optimum range of P concentration is often wider when nitrate is used than when ammonium salt is used as the source of N.

Chu, S. P. 1943.
The Influence of the Mineral Composition of the Medium on the Growth of Planktonic Algae. Part II. The Influence of the Concentration of Inorganic Nitrogen and Phosphate Phosphorus. Journal of Ecology, Vol. 31, No. 2, pp. 109–148.

The upper limit of concentrations of nitrogen and phosphorus for optimum growth of the plankton organisms studied is always higher than the highest concentrations occurring in ordinary waters, so that their growth is unlikely ever to be unfavorably affected by too high a concentration of nitrogen or phosphorus. On the other hand, the concentration of nitrogen and phosphorus in nearly all natural waters frequently falls below, or in some never reaches, the lower limits for optimum growth. The lower limit of the optimum range of nitrogen concentration differs for different organisms. It generally varies approximately from 0.3 to 1.3 and sometimes to 2.6 or 5.3 mg/l when an ammonium salt is the source of nitrogen; and from 0.3 to 0.9 mg/l when nitrate is the source of nitrogen. Below these limits the growth rate decreases with decreasing concentration of nitrogen. The upper limit of the optimum range of nitrogen concentration varies approxi-

mately from 5.3 to 13 mg/l when an ammonium salt is the source of nitrogen, and from 3.5 to 17 mg/l when nitrate is the source of nitrogen. Beyond these limits there is an increasing inhibiting effect. Optimum growth of all organisms studied can be obtained in nitrate-nitrogen concentrations from 0.9 to 3.5 mg/l and phosphorus concentrations from 0.09 to 1.8 mg/l, while a limiting effect on all organisms will occur in nitrogen concentrations from 0.1 mg/l downward and in phosphorus concentrations from 0.009 mg/l downward.

The lower limit of optimum range of phosphorus concentration varies from about 0.018 to about 0.09 mg/l; and the upper limit from 8.9 to 17.8 mg/l when nitrate is the source of nitrogen, while it lies at about 17.8 for all the planktons studied when ammonium is the source of nitrogen. Low phosphorus concentrations may, therefore, like low nitrogen concentrations, exert a selective limiting influence on a phytoplankton population. The nitrogen concentration determines to a large extent the amount of chlorophyll formed. Nitrogen concentrations beyond the optimum range inhibit the formation of chlorophyll in green algae.

Comly, H. H. 1945.
Cyanosis in Infants Caused by Nitrates in Well Water. Journal American Medical Association, Vol. 129, pp. 112–116.

The causative factor producing serious blood changes (methemoglobinemia) in infants was first reported in 1945 in polluted water containing 140 mg/l nitrate nitrogen (NO_3-N) and 0.4 mg/l nitrite (NO_2) ion in one case; in the second case, 90 mg/l nitrate nitrogen and 1.3 mg/l nitrite ion.

Cook, B. B. 1962.
The Nutritive Value of Waste-Grown Algae. American Journal of Public Health, Vol. 52, No. 2, pp. 243–251.

The proximate analysis and amounts of calcium, phosphorus, iron, carotene, ascorbic acid, and eight B-vitamins have been determined in single-celled algae grown in symbiosis with bacteria in open, outdoor ponds, on sewage and organic wastes. Dried *Scenedesmus quadricauda* and *Chlorella* were found to contain 40 to 50 percent protein and extremely large amounts of minerals. Compared with beef on a weight basis, the algae contained more of all the B-vitamins, except B_{12}, than did beef. Because of the unpleasant odor and flavor of the algae, it would be extremely improbable that it would be eaten unless effectively masked with other foods in combination.

Curl, H., Jr. 1959.
The Origin and Distribution of Phosphorus in Western Lake Erie. Limnology and Oceanography, Vol. 4, No. 1, pp. 66–76.

The phosphate phosphorus distribution in western Lake Erie in May 1951 and the average concentration throughout 1950–1951 were shown to be a result of the drift current pattern and the discharge of the Maumee and Detroit Rivers. The bedrock in the lake appears to provide negligible quantities. The Detroit River supplies 405 metric tons per year at an average concentration of 2.6 μg PO_4-P/l, and the Maumee River supplies 125 tons per year at a concentration of 16 μg PO_4-P/l. There is a loss of soluble phosphorus, possibly as precipitating ferric phosphate and by adsorption onto ferric hydroxide. The bottom sediments contained an average of 56.9 mg P/g of dried mud.

"Maumee River water averaged 50 μg Fe^{+++}/l in 1950–51, which could be present as hydroxide or as ferric phosphate. In the latter state 50 μg of iron would be combined stoichiometrically with 27 μg of phosphorus. In an excess of ferrous ion, ferric hydroxide could be adsorbed onto the colloid, and the complex would then precipitate. A mechanism such as this would account for the high phosphorus values of the lake sediments. If 27 μg of the average of 43 μg PO_4-P/l in Maumee River water were to be combined as ferric phosphate and lost by precipitation to the river and estuary bed, 16 μg would remain."

Phosphate phosphorus and turbidity in the lake are positively correlated and evidence from turbidity data indicates that the lake is enriched by a thin-layered tongue of water from the south shore streams which flows over or under the clearer, nutrient-poor water, and then mixes vertically with it.

Removal of fish by man accounts for an annual loss of 29 metric tons, or 6 percent of the average annual input. Approximately 94 metric tons may be held temporarily as phytoplankton. The density of the diatom cells was taken as 1.1 and the average wet weight as organic matter of freshwater and marine phytoplankton had been found to be 5 percent.

Curry, J. J. and S. L. Wilson. 1955.
Effects of Sewage-borne Phosphorus on Algae. Sewage and Industrial Wastes, Vol. 27, No. 11, pp. 1262–1266.

Since the formation of Lake Zoar on the Housatonic River in Connecticut by the construction of the Stevenson Dam, the number of algae and aquatic weeds in the lake have increased considerably, and a

study of the problem was carried out in 1954. Phosphorus concentrations in the lake varied from 12 to 41 ppb and averaged about 25 ppb.

Preliminary studies using 200 mg/l alum in 4,000-gallon batch treatments with a mixing time of 10 minutes and a settling time of 2 hours treating sewage plant effluents having a phosphorus content of 3.61 to 4.62 mg/l gave 96.7 percent removal of phosphates.

Deevey, E. S., Jr. 1940.
Limnological Studies in Connecticut. V. A Contribution to Regional Limnology. American Journal of Science, Vol. 238, pp. 717–741.

Examination of 49 lakes in Connecticut and New York provided data showing a close relationship between the geology of the region and the quantity of phytoplankton in the lakes. Lakes overlying soluble sedimentary rocks, rich in iron, had abundant phytoplankton and a high phosphorus concentration; those surrounded by metamorphic rock were poor in phytoplankton. In order of importance in the control of phytoplankton growth was phosphorus first, followed by nitrogen.

Lakes of Connecticut resemble those of northeastern Wisconsin with respect to the amounts of soluble and total phosphorus. The lakes in both regions "live beyond their means" with regard to their phosphorus content; under arctic conditions, the phosphorus oligotype would result in oligotrophy.

Domogalla, B. P. and E. B. Fred. 1926.
Ammonia and Nitrate Studies of Lakes Near Madison, Wisconsin. Journal of the American Society of Agronomy, Vol. 18, pp. 897–911.

Surface and bottom samples of 2 to 5 liters taken each two weeks were analyzed for organic nitrogen, ammonia nitrogen, nitrate nitrogen, and phosphate phosphorus.

Of the five lakes examined, the water of Lake Waubesa (Madison, Wisconsin) showed a consistently higher organic nitrogen content than did the others and, also, the greatest concentration of phytoplankton. The range was 980 mg per cubic meter in June to 1,470 mg per cubic meter in the latter part of August.

In all the lakes, ammonia concentration increased during March and April but began to decrease with the increase in plankton concentration.

The nitrate changes followed the same variation as organic nitrogen and ammonia. Concentration of phosphate phosphorus decreased with increasing concentration of plankton.

Analysis of lake water following heavy rains showed a marked increase in the concentration of soluble phosphorus and the different forms of nitrogen.

Domogalla, B. P., E. B. Fred, and W. H. Peterson. 1926a.
Seasonal Variation in the Ammonia and Nitrate Content of Lake Waters. Journal American Water Works Association, Vol. 15, pp. 369–385. [From Putnam and Olson, 1959]

In Lake Mendota, Wisconsin, beginning with the fall overturn, there was little change in soluble nitrogen until February and March; by the time the spring overturn occurred in April, there was an increase of 300 percent in free ammonia and 200 percent in nitrate nitrogen in the bottom levels.

In Lake Michigan, at the surface, the concentration of ammonia was 102 mg per cubic meter; nitrate was 50 mg per cu. m. At 72 meters depth, ammonia was 204 mg per cu. m.; nitrate was 79 mg per cu. m.

Domogalla, B. P., C. Juday, and W. H. Peterson. 1925.
The Forms of Nitrogen Found in Certain Lake Waters. Journal of Biological Chemistry, Vol. 63, pp. 269–285. [From Putnam and Olson, 1959]

Lake Mendota, Wisconsin, contained more than 9 times as much soluble nitrogen as it did total plankton nitrogen. Ammonia nitrogen varied from 11.6 to 39.2 mg. per cu. m. during a 1-year period. Most of the soluble nitrogen was formed at the bottom of the lake, spreading upward toward the surface. At the spring and fall overturns, the soluble nitrogen content of the lake was uniform. As soon as stratification occurs, the concentration of soluble nitrogen in the hypolimnion exceeds that in the epilimnion.

Donahue, R. L. 1961.
Our Soils and Their Management. The Interstate Printers and Publishers, Inc., Danville, Illinois, 568 pp.

Nitrogen in representative surface soils varies from 0.2 percent in the sandy soils of Florida and Virginia to approximately 0.15 percent

in a limestone soil in the Lake States. The amount of nitrogen in a soil is proportional to the amount of organic matter. The percentage of nitrogen multiplied by 20 usually equals the percentage of organic matter. Phosphorus varies from a trace to 0.3 percent in surface soils. Nitrogen and phosphate in a productive soil average about 0.1 pound per cubic foot each.

The pounds of plant nutrients required per acre for good acre yields were given as follows:

	Nutrients per acre		
	Pine trees (annual growth)	Corn (100 bushels)	Alfalfa (6 tons)
Nitrogen (N)	24	160	300
Phosphate (P_2O_5)	6	55	75
Boron	.....	0.15	0.7

As a general rule, 1 ton of livestock, regardless of kind, will void about 1 ton per month of excrement based on an equivalent water content of 65 percent. The average composition in pounds per ton of fresh animal manures was given as follows:

	Nitrogen(N) (pounds)	Phosphate (P_2O_5) (pounds)
Cattle	10	4
Horses	15	3
Hogs	10	7
Sheep	20	5
Poultry	30	15

Sawdust contains 4 lbs N and 2 lbs P_2O_5 per ton of dry material: wheat straw 10 and 3 pounds, respectively; alfalfa hay, 48 and 10.

Activated sewage sludge contains 5.6 percent nitrogen (N) and 5.7 percent phosphorus (P_2O_5); digested sludge, 2.4 and 2.7 percent respectively.

The pounds of fertilizer recommended per acre per year on grassland varies from 50 in the Pacific and Great Plains regions to 450 pounds in the northeast and southeast. The percentage of the recommended amount that is applied varies from 0.8 to 16 percent in the above named regions.

On the average 3,500 pounds of tree leaves per acre, on the oven-dry basis, fall to the ground each year (Metz, 1954). This compares with approximately 1,700 pounds from jack pines and red pine stands in Minnesota (Alway and Zon, 1930) and between 3,000 and 4,000 pounds from New England red pine forests (Lunt, 1948). The nutrients

returned annually to the soil by forest tree leaves were cited as follows (Chandler 1941 and 1943):

	Pounds per acre returned annually	
	Nitrogen	Phosphorus
Conifer	23.6	1.8
Hardwood	16.6	3.3

Metz, L. J., 1954. Forest Floor of South Carolina Piedmont Stands. Soil Sci. Soc. Amer. Proc.

Alway, F. J. and R. Zon, 1930. Quantity and Nutrient Content of Pine Leaf Litter. Journ. Forestry, Vol. 28, pp. 715–727.

Lunt, H. A., 1948. The Forest Soils of Connecticut. Connecticut Agr. Exp. Station Bul. No. 523.

Chandler, R. F., Jr., 1941. The Amount and Nutrient Content of Freshly Fallen Leaf Litter in the Hardwood Forests of Central New York. Journ. Amer. Soc. Agron., Vol. 33.

Chandler, R. F., Jr., 1943. Amount and Mineral Nutrient Content of Freshly Fallen Needle Litter of Some Northeastern Conifers. Soil Sci. Soc. Amer. Proc., Vol. 8.

Douglas, J. S. 1959.
Hydroponics
Oxford University Press, London, 144 pp.

The dry fertilizer salts, which are used in hydroponics, go into solution with the water present in the beds of aggregate forming a liquid plant food. A suitable nutrient solution would contain:

Element	Mg/l.	Element	Mg/l.
Nitrogen	200 to 400	Iron	2 to 10
Potassium	100 to 200	Manganese	0.5 to 5
Phosphorus	80 to 100	Boron	0.5 to 5
Magnesium	50 to 100	Copper	0.5
Calcium	300 to 500	Zinc	1.0

Variations of these concentrations have been used with success, and much depends on locality, climate, and light conditions.

Dugdale, V. A. and R. C. Dugdale. 1962.
Nitrogen Metabolism in Lakes. II. Role of Nitrogen Fixation in Sanctuary Lake, Pennsylvania. Limnology and Oceanography, Vol. 7, No. 2, pp. 170–177.

A study of the rates of nitrogen fixation using N^{15} as a tracer was made in Sanctuary Lake, Pennsylvania. The rates of fixation in the

lake were found to be considerable (at least 1 percent per day of the organic or "reduced" nitrogen already present at the beginning of the experiment) during the summer and appeared to be correlated with the presence of a dense population of *Anabaena*. Laboratory experiments supported the idea that photosynthetic organisms were responsible since a strong correlation with light was found.

Dugdale, V. A. and R. C. Dugdale. 1965.
Nitrogen Metabolism in Lakes. III. Tracer Studies of the Assimilation of Inorganic Nitrogen Sources. Limnology and Oceanography, Vol. 10, No. 1, pp. 53–57.

The activity of the phytoplankton in Sanctuary Lake, Pennsylvania, was found to fall in three clearly defined periods: (1) a spring bloom when NH_3-N, NO_3-N, and N_2-N are assimilated strongly and in that order of importance; (2) a midsummer period when weak assimilation of NH_3-N and N_2-N, but not NO_3-N, occurred; and (3) a fall bloom with intense nitrogen fixation and some NH_3-N uptake, but characterized by low NO_3-N activity. Nitrogen fixation and NH_3-N uptake appear to proceed concurrently, although ammonia uptake dominates in spring and nitrogen fixation dominates in fall.

Dugdale, R. C., J. J. Goering, and J. H. Ryther. 1964.
High Nitrogen Fixation Rates in the Sargasso Sea and the Arabian Sea. Limnology and Oceanography, Vol. 9, No. 4, pp. 507–510.

Nitrogen fixation rates were measured in the Sargasso Sea and the Arabian Sea using the N^{15} method. It was considered a virtual certainty that the large-scale blooms of *Trichodesmium* from tropical oceanic regions were nitrogen-fixing blooms analogous to those observed in lakes associated with several species of *Anabaena*. The ability to fix nitrogen was clearly shown to lie with the *Trichodesmium* colonies (that is, the alga and any associated bacteria or fungi).

Dugdale, R. C. and J. C. Neess. 1961.
Recent Observations on Nitrogen Fixation in Blue-Green Algae. Algae and Metropolitan Wastes, U.S. Public Health Service, SEC TR W61–3, pp. 103–106.

The authors cite necessary conditions for intense nitrogen fixation: (1) the general physical and nutritional characteristics of the body of water must be such as to encourage the growth of blue-green algae,

(2) some factor(s) must operate to reduce the concentrations of the various forms of combined nitrogen to very low levels, (3) an adequate supply of phosphorus would appear to be critical, and (4) certain elements (calcium, boron, and molybdenum) in trace amounts are known to be specifically necessary to permit nitrogen fixation by particular species of blue-green algae. Dilute sea-water is a reasonably good medium for nitrogen-fixing blue-green algae, perhaps because it contains favorable amounts of trace elements. It seems possible that some of these elements are concentrated in sewage, resulting under certain circumstances in the stimulation of nitrogen fixation by this material.

Engelbrecht, R. S. and J. J. Morgan. 1959.
Studies on the Occurrence and Degradation of Condensed Phosphate in Surface Waters. Sewage and Industrial Wastes. Vol. 31, No. 4, pp. 458–478.

Rudolfs (1947) reported an average phosphate concentration in raw sewage of 5.2 mg/l as P_2O_5. The average concentration in effluents from biological treatment was 0.5 mg/l as P_2O_5. Rudolfs indicated that per capita phosphate contributions from domestic raw sewage were from 3.3×10^{-3} to 7.5×10^{-3} lb/day as P_2O_5. Sawyer (1952) calculated that the contribution of phosphates used in the detergent and water softening industry during 1950 amounted to 10×10^{-3} lb/day/cap as P_2O_5. Estimates by the Association of American Soap and Glycerine Producers indicated a synthetic detergent consumption of 16 lb/cap for the year 1955. This corresponded to a contribution of 12×10^{-3} lb/day/cap as P_2O_5 to sewage by household synthetic detergents alone. Sawyer (1944) reported total phosphorus land drainage of approximately 1.6 lb/day sq mile, of which approximately 75 percent was organic. Silvey (1953) observed that organic phosphorus in plant leaves may be oxidized to soluble phosphates. Sudden additions of water through rainfall could wash phosphates to the stream. Dietz and Harmeson (1956) concluded that the average total phosphate concentration in Illinois surface waters was 0.648 mg/l as P_2O_5. Solely on the basis of stream analysis data, they estimated that the phosphate contribution from domestic sewage would range from 7.67×10^{-3} to 27.3×10^{-3} lb/day/cap.

Results from 9 samples collected at 8 lake and reservoir sources believed to be relatively free of domestic pollution gave a mean orthophosphate concentration of 0.036 mg/l P_2O_5 and a mean value of orthophosphate plus the maximum inorganic condensed (hydrolyzable) P_2O_5 of 0.091 mg/l.

The analytical results from 27 samples from streams in the major Illinois River basin suspected to contain significant amounts of treated

and untreated wastes gave an average orthophosphate concentration of 0.411 mg/l P_2O_5 and an average orthophosphate plus maximum inorganic condensed P_2O_5 of 0.657 mg/1.

The mean orthophosphate concentration among 3 trickling filter sewage treatment plant effluents and 1 activated sludge plant effluent in Illinois in 1956 ranged from 11.6 to 24.2 mg/1 P_2O_5 and the per capita contributions from 9.4 to 24.2×10^{-3} pounds per day. In addition, the maximum inorganic condensed P_2O_5 concentration ranged from 0.8 to 2.1 mg/1 and the per capita contribution from 0.7 to 2.25×10^{-3} pound per day.

Rudolfs, W. 1947. Phosphates in Sewage and Sludge Treatment. I. Quantities of Phosphates. Sewage Works Journal, Vol. 19, No. 1, pp. 43.

Sawyer, C. N. 1952. Some New Aspects of Phosphates in Relation to Lake Fertilization. Sewage and Industrial Wastes, Vol. 24, No. 6, pp 768–776.

Sawyer, C. N. 1947. Fertilization of Lakes by Agricultural and Urban Drainage. Jour. New England Water Works Assn., Vol. 61, No. 2, pp. 109–127.

Silvey, J. K. G. 1953. Relation of Irrigation to Taste and Odors. Journal American Water Works Assoc., Vol. 45, No. 11, pp. 1179.

Dietz, J. C. and R. H. Harmeson. 1958. Phosphate Compounds Occurring in Illinois Surface Waters. Proceedings 12th Indiana Waste Conference, Purdue University, Vol. 94, pp. 285.

Engelbrecht, R. S. and J. J. Morgan. 1961.
Land Drainage as a Source of Phosphorus in Illinois Surface Waters. Algae and Metropolitan Wastes, U.S. Public Health Service, SEC TR W61–3, pp. 74–79.

Phosphorus carried to surface waters may be in the simple orthophosphate form or as a soluble hydrolyzable phosphate, or it may be adsorbed on clay particles. As adsorbed forms of phosphate increase in amount their solubility in water increases rapidly. Results are reported for 100 samples from the Kaskaskia River basin that has farm lands containing 40 to 50 pounds of available P_2O_5 per acre, and are drained by tile drains. High rainfalls and high rates of percolation exist. At one station that receives no domestic sewage and receives runoff from a cultivated drainage area of 11 square miles, ortho plus hydrolyzable P_2O_5 averaged 0.1 pound of P_2O_5 per day per square mile of drainage area. For the 100 samples, the calculated pounds of P_2O_5 per day per square mile varied from 0 to 58 for ortho plus hydrolyzable with a mean of 1.4. The amount of agricultural phosphate transported to streams undoubtedly depends upon the: nature and amount of phosphates in the soil, mode of drainage, topography, intensity and distribution of rainfall, rates of infiltration and percolation, and probably other factors.

Fippin, E. O. 1945.
Plant Nutrient Losses in Silt and Water in the Tennessee River System. Soil Science, Vol. 60, pp. 223–239.

The average loss of plant nutrients per acre of row crops in Tennessee River System for the year 1939 was: 84.6 pounds of calcium, 97.9 pounds of magnesium, 212.2 pounds of potassium, 13.0 pounds of phosphorus (all expressed as oxides) and 23.8 pounds of nitrogen.

Fitzgerald, G. P. 1965. Personal Communication.

The following data were supplied:

A. *Concentration of Salts Used in Algal Media at University of Wisconsin (mg./l.)*

Salt	Gerloff's [1]	ASM [2]	Gorham's [3]	Allen's [4]	Myers' [5]
NH_4Cl				53	
$NaNO_3$	136	85	425	1,000	
KNO_3					1,010
KH_2PO_4					1,360
K_2HPO_4	87	17.4	87	261	
$MgCl_2$		16			
$MgSO_4 \cdot 7H_2O$	49	49	74	123	2,465
$CaCl_2 \cdot 2H_2O$	36	14.7	36	58	
Fe Citrate	6		6		
$FeCl_3$		.32		1	
$Fe(NO_3)_3$					25
$Na_2EDTA \cdot 4H_2O$	50		50		
$MnCl_2$	33		33		
$CuSO_4$ anh.	5		5		
Na citrate					588
EDTA		7.4	7		

[1] Fitzgerald, G. P., G. C. Gerloff, and F. Skoog, Studies on Chemicals with Selective Toxicity to Blue-green Algae, Sew. and Ind. Wastes, 24, 888–896 (1952).
[2] Gerloff, G. C. and F. K. Gorham, Growth of *Microcystis aeruginosa* Kütz in a precipitation-medium buffered with tris, Can. J. Microbiol., 7, 869–881 (1961).
[3] Hughes, E. O., F. K. Gorham, G. A. Zehnder, Toxicity of a unialgal culture of *Microcystis aeruginosa*, Can. J. Microbiol., 7, 379–390 (1958).
[4] Allen, M. B., The Cultivation of Myxophyceae, Arch. Microbiol., 17, 34–53 (1952).
[5] Durbin, J. E., Jr., *Algal Culture From Laboratory to Pilot Plant*. Carnegie Inst. Wash., Pub. No. 600 (1959).

Fleigg, N. G. and G. W. Reid. 1958.
Effects of Nitrogenous Compounds on Stream Conditions. Sewage and Industrial Wastes, Vol. 26, No. 9, pp. 1125–1134.

In laboratory experiments to determine which forms of nitrogen were most readily utilized by microorganisms, concentrations up to

about 15 mg/l showed no significant difference in the utilization of the three inorganic forms (nitrite, nitrate, and ammonia). Phosphorus was supplied by a solution of dibasic potassium phosphate. With higher concentrations of nitrogen, growth of algae was accelerated and in practice this would tend to concentrate the organisms in a shorter stretch of the stream.

Gerloff, G. C., G. P. Fitzgerald, and F. Skoog, 1950.
The Isolation, Purification, and Nutrient Solution Requirements of Blue-green Algae. Symposium on the Culturing of Algae, Charles F. Kettering Foundation, Dayton, Ohio, pp. 27–44.

The composition of basic culture solutions used for mineral nutrition experiments with *Cucumbioris Penicyptis* were given as follows:

Component	Grams per liter	PPM of essential elements
$Ca(NO_3)_2$	0.4918	N 14
$MgSO_4 \cdot 7H_2O$	.4925	NO_3 70
KH_2PO_4	.1360	P 31
$MgSO_4 \cdot 4H_2O$	.1848	PO_4 95
$NaNO_3$	.1699	K 39
$CaCl_2 \cdot 2H_2O$	.1323	Ca 40
Iron citrate	.005	Mg 24
$MnSO_4 \cdot 4H_2O$	.0045	
$ZnSO_4 \cdot 7H_2O$	.0015	
$CuSO_4 \cdot 5H_2O$	.0005	

Hoagland's A to Z solution is added to the culture solution at ¼ the strength specified for higher plants.

The minimum concentration of each element for the optimum growth of *Cucumbioris Penicyptis* would have the following composition in ppm: nitrogen, 13.6; phosphorus, 0.31; sulfur, 0.32; potassium, 2.26; magnesium, 0.13; iron, 0.03; and only traces of calcium derived from the inoculum and from impurities in the nutrients.

Gerloff, G. C. and F. Skoog, 1954.
Cell Content of Nitrogen and Phosphorus as a Measure of their Availability for Growth of *Microcystis aeruginosa*. Ecology, Vol. 35, No. 3, pp. 348–353.

The estimation of nutrient supplies by analysis of water collected from the area in which the algae are present may be of little value because the total supply of a nutrient element is dependent on the total volume as well as the concentration of the solution from which it is absorbed. This effective volume will vary with the extent to which the algae are moved about and come in contact with different

Tamm, C. O. 1953.
Growth, Yield, and Nutrition in Carpets of a Forest Moss. Meddelanden från Statens Skogsforskning Institut, Vol. 43, pp. 1–140. (From Putnam and Olson, 1960.)

Rainwater was collected in an open field using funnels and flasks of stainless steel. Analysis of the collected rainwater yielded the following data (mg/l):

	NH_3-N	P	K	Na	Ca	Fe	Mn	SiO_2
Nov. 1–17, 1951	0.8	0.1	0.6	1.0	0.7	0.02	0	0.4
Nov. 17–24, 1951	.2	.1	.3	.7	.2	.02	0	--------
July 17–Aug. 12, 1952	.9	--------	.3	.3	.5	--------	--------	--------
Aug. 12, 15, 1952	.5	--------	.3	.5	.2	--------	--------	--------

During the summer and autumn of 1952, rainwater was collected during five different periods, using glass funnels and flasks. A total of 227 mm of water fell during the sampling period carrying down, as an average from three different sampling vessels, 0.97 mg K, 1.41 mg Na, and 0.91 mg Ca per dm^2.

Tanner, H. A. 1960.
Some Consequences of Adding Fertilizer to Five Michigan Trout Lakes. Transactions American Fisheries Society, Vol. 89, No. 2, pp. 198–205.

Inorganic fertilizer (10–6–4) was applied to four of a group of six Michigan trout lakes ranging in size from 2.6 to 5.9 acres at rates varying from 80 to 650 pounds per acre. The thermocline in the three lakes receiving the most fertilizer shifted to a more shallow position. Three of the fertilized lakes decreased in total alkalinity at a greater rate than did the two lakes not fertilized. Fertilization resulted in the oxygen being depleted from the hypolimnion and some oxygen reduction occurred in the thermocline. The volume of oxygenated water remaining under the ice during the critical period of late winter was reduced in the fertilized lakes, and lakes fertilized at the highest rate very nearly approached winterkill conditions. The reduction of oxygen both in summer stagnation periods and in late winter was more severe after the second season of fertilization. Author cites Einsele (1938) as indicating that, in general, when iron is present in the hypolimnion, it combines with phosphorus as ferric phosphate in the presence of oxygen. The precipitate formed is insoluble and results in the removal of phosphorus from the lake water. If, however, oxygen is absent when the iron and phosphorus combine, the product is a soluble ferrous phosphate, some of which will be reused. Mortimer (1941) has indicated that the processes of reduction usually return

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the nutrient material in forms more usable by plants and bacteria than do the processes of oxidation. Eutrophication is extremely slow while the lake is oligotrophic. When the lake assumes the characteristics of a eutrophic lake, which includes lack of oxygen in the hypolimnion during the summer stagnation period, continued eutrophication and extinction become rapid.

Einsele, W. 1938. Über chemische und colloidale-chemische Vorgänge in Eisen-Phosphor-Systemen unter limnochemischen und limnogeologischen Gesichspunken. Arch. f. Hydrobiol., Vol. 33, pp. 361–387.

Mortimer, C. H. 1941. The Exchange of Dissolved Substances between Mud and Water in Lakes. I and II. Journal of Ecology, Vol. 29, No. 2, pp. 280–329.

Tucker, A. 1957.
The Relation of Phytoplankton Periodicity to the Nature of the Physico-Chemical Environment with Special Reference to Phosphorus. I. Morphometrical, Physical and Chemical Conditions. American Midland Naturalist, Vol. 57, pp. 300–333.

The investigation was carried on for 16 months at Douglas Lake, Michigan, with water samples being collected and phosphorus determinations being made every two weeks.

At the surface, total phosphorus fluctuated between 7 and 14 micrograms per liter, at the 12-meter depth (lower limit of the epilimnion) between 7 and 15 micrograms per liter. At the 20-meter depth, between July 3 and September 16, the amount of total phosphorus increased from 10 micrograms per liter to 641. Seasonal variation in inorganic phosphorus (soluble) followed closely the variation in total phosphorus, although smaller in amount. Analysis of a vertical series of samples showed that the most constant fraction of phosphorus was the soluble organic phosphorus, never exceeeding 9 micrograms per liter regardless of the depth at which the sample was taken.

The pH was 8.0–8.4 in the epilimnion and between 7.0 and 8.0 in the hypolimnion.

Tucker, A. 1957a.
The Relation of Phytoplankton Periodicity to the Nature of the Physico-Chemical Environment with Special Reference to Phosphorus. II. Seasonal and Vertical Distribution of the Phytoplankton in Relation to the Environment. American Midland Naturalist, Vol. 57, pp. 334–370.

Toward the end of the summer, oxygen was absent at the bottom of the hypolimnion in Douglas Lake, Michigan, but phosphorus could not be detected in this bottom area until about 8 weeks after the disap-

pearance of the oxygen. It was concluded that the reason for the lack of analyzable phosphorus was that iron and phosphorus can exist independently only when oxygen is absent and that if oxygen is introduced, the iron and phosphorus will combine to form an insoluble ferric phosphate precipitate. When oxygen disappears from bottom waters, the ferric complexes are reduced, forming ferrous complexes which are soluble.

Tucker, J. M., D. R. Cordy, L. J. Berry, W. A. Harvey, and T. C. Fuller. 1961.
Nitrate Poisoning in Livestock. California Agricultural Experiment Station Extension Service, University of California Circular 506, 9 pp.

Nitrates, absorbed from the soil by most plants, serve as a source of nitrogen which plants convert into proteins and other nitrogen-containing compounds. Normally functioning plants usually contain relatively small amounts of nitrate because the nitrate is converted into other nitrogenous compounds almost as soon as it is absorbed. Under certain conditions, however, some plants may accumulate fairly high concentrations of nitrate. While these concentrations are not toxic to the plant itself, animals feeding on such plants may sometimes suffer fatal poisoning.

Nitrate itself is not very toxic, but is readily converted into nitrite. Probably most of the conversion of nitrate to nitrite takes place in the animal digestive tract, although some field studies indicate that nitrite may already be present in the plants before they are eaten. Nitrite converts the hemoglobin in red blood cells to methemoglobin, which cannot transport needed oxygen from the lungs to the body tissues. Thus, animals affected with nitrate poisoning show general symptoms of oxygen deficiency.

Ruminants, particularly cattle, are the principal victims of nitrate poisoning because of the large amounts of plant material they eat and the action of microorganisms in the rumen. Sheep and swine are less susceptible. There appears to be few recorded cases of horses dying from nitrate poisoning under pasture or range conditions.

Factors affecting nitrate accumulation in plants include the stage of the plant's growth (the pre-blooming period has the highest accumulation), an ample supply of available nitrate in the soil, an adequate moisture supply, an acid rather than an alkaline soil, relatively low temperatures (around 55° F), and reduction in light intensity. An excess of phosphate tends to retard nitrate absorption.

Plants are considered as potentially toxic if they contain nitrate amounting to more than 1.5 percent expressed as KNO_3 on a dry weight basis. This is 15,000 ppm KNO_3 or 2,078 ppm N.

Plants that have been involved in nitrate poisoning or are capable of accumulating appreciable amounts of nitrate include:

PLANT	COMMON NAME
Amaranthus blitoides	Prostrate pigweed.
A. graecizans	Tumbling pigweed.
A. retroflexus	Rough pigweed.
Ammi majus	Bishop's weed.
Amsinckia douglasiana	Douglas' fiddleneck.
A. intermedia	Common fiddleneck.
Apium graveolens	Celery.
Avena sativa	Oats.
Beta vulgaris	Sugar beet.
B. vulgaris var. *rapa*	Mangel.
Bidens frondosa	Beggar-ticks.
Brassica campestris	Turnip.
B. napobrassica	Rutabaga .
B. napus	Rape.
B. oleracea vars	Brocolli, Kale, Kohlrabi.
B. rapa	Turnip
Bromus catharticus	Rescue grass.
Chenopodium album	Lamb's-quarters.
C. ambrosioides	Mexican tea.
C. californicum	Soap plant.
C. murale	Nettle-leaf goosefoot.
Cirsium arvense	Canada thistle.
Cleome serrulata	Rocky Mountain bee plant.
Conium maculatum	Poison hemlock.
Convolvulus arvensis	Wild morning-glory.
Cucumis sativa	Cucumber.
Cucurbita maxima	Hubbard squash.
Daucus carota	Carrot.
Eleusine indica	Goose grass.
Euphorbia maculata	Spotted spurge.
Glycine max	Soybean .
Gnaphalium purpureum	Purple cudweed .
Haplopappus venetus	Coast goldenbush.
Helianthus annuus	Common sunflower.
Helianthus tuberosus	Jerusalem artichoke.
Hordeum vulgare	Barley.
Kochia americana	Fireball.
Lactuca sativa	Lettuce.
L. scariola	Prickly lettuce.
Linum usitatissimum	Flax .
Malva parviflora	Cheeseweed.
Melilotus officinalis	Yellow sweet clover.
Montia perfoliata	Miner's lettuce.
Panicum capillare	Witch grass.
Parkinsonia aculeata	Horse bean.
Pastinaca sativa	Parsnip.
Plagiobothrys sp.	Popcorn flower.
Rafinesquia californica	California chicory.
Raphanus sativus	Radish.
Salsola kali	Russian thistle.

PLANT	COMMON NAME
Secale cereale	Rye.
Silybum marianum	Milk thistle.
Solanum carolinense	Carolina horse nettle.
S. nigrum	European black nightshade.
Sonchus asper	Prickly sow-thistle.
S. oleraceus	Common sow-thistle.
Sorghum halepense	Johnson grass.
S. sudanense	Sudan grass.
S. vulgare	Sorghum.
Thelypodium lasiophyllum	California mustard.
Tribulus terrestris	Puncture vine.
Triticum aestivum	Wheat.
Verbesina enceliodes	Crownbeard.
Zea mays	Corn.

Vaccaro, R. F. 1964.
Available Nitrogen and Phosphorus at the Biochemical Cycle in the Atlantic of New England. Journal of Marine Research, Vol. 21, No. 3, pp. 284–301.

During August, when only trace amounts of nitrate persist in the photic layer, ammonia appears to be the major source of available nitrogen. By late summer, nitrogen assimilation by marine phytoplankton in the surface waters off New England had reduced nitrate to trace amounts close to the limit of sensitivity of the analytical method employed. Ammonia persists throughout the summer at about half of its winter concentration, and by August it has become the most abundant source of plant nitrogen. Conversely during winter, although higher concentrations of each type of nitrogen are present, nitrate-nitrogen is five or six times more abundant than ammonia. It appears that the relative abundance of ammonia as opposed to nitrate during summer in the euphotic waters off New England coincides with maximum stratification of the water column because of increased surface temperatures. Until the occurrence of active nitrification within the upper layer is more conclusively demonstrated, it must be assumed that, at such times, the major impetus to the nitrogen cycle is provided by ammonia because of its more rapid exchange between organisms and environment and because of its direct addition from the atmosphere in association with rain. The annual variation in available phosphorus within these waters, unlike that of nitrogen, is much less pronounced, and excess amounts are the rule throughout the year.

The analyses of particulate nitrogen and phosphorous provide a quantitative basis for assessing the extent of seasonal adaptation to the summer supply of available nitrogen and phosphorus. When nitrate was virtually absent from the upper fifty meters during August, the

phytoplankton contained nitrogen and phosphorus on a dry weight basis at a ratio corresponding to 12:1. This condition was accompanied by generally higher ratios up to 20:1 in the coarser net material. Competent ratios measured by Harris and Riley (1956) were cited for Long Island Sound as 12.6:1 for August phytoplankton and 20.6:1 for July zooplankton. For March of the same year, when large amounts of available nitrogen were present, the same authors reported a ratio of 17.2:1 for Long Island Sound phytoplankton.

Harris, E. and G. A. Riley. 1956.
Oceanography of Long Island Sound, 1952–54.
VIII. Chemical Composition of the Plankton.
Bull. Bingham Oceanogr. Coll., Vol. 15, pp. 315–323.

Vallentyne, J. R. 1952.
Insect Removal of Nitrogen and Phosphorus Compounds From Lakes. Ecology, Vol. 33, pp. 573–577; Water Pollution Abstracts, Vol. 26, No. 11, Abs. No. 1861.

To determine the amounts of nitrogen and phosphorus removed from lakes by aquatic insects which leave the water in the adult stage, a study was made of the concentration of total nitrogen and phosphorus in adult insects trapped as they emerged from the water in Lake Opinicon, Ontario. On an average, 136 insects emerged per day per square meter of surface and these had a fresh weight of 69.2 mg and contained 2.26 mg of total nitrogen and 0.15 mg of total phosphorus. It is calculated that in Winona Lake, Indiana, where the amount of organic sediment has been determined, the loss of organic matter by emergence of insects was less than 1 percent of the amount of organic sediment deposited annually.

VanVuran, J. P. J. 1948.
Soil Fertility and Sewage. Dover Publications Inc., New York, 236 pp.

The average human inhabitant of a European city excretes 107 pounds per year solids and 964 pounds per year liquids for a total of 1,071 pounds. This contains 75.8 pounds of dry matter, 11.4 pounds of nitrogen and 2.6 pounds of phosphoric acid. The average composition of fresh human feces is 1 percent nitrogen and 1.10 percent phosphoric oxide (PO); the composition of urine is 0.6 percent nitrogen and 0.17 percent PO.

The quantity of manure voided by animals varies with type, climate and food. Roughly for 1,000 pounds of live weight, cows excrete 22,000 pounds of solids and 6,800 pounds of liquids per year; horses,

13,000 and 2,600 pounds, respectively. Yearly fertilizer constitutents were given as follows:

	Nitrogen (pounds)	Phosphoric acid (pounds)
Horse	128	43
Cow	156	38
Sheep	119	44
Pig	150	104

The water hyacinth was first introduced into the United States from Venezuela and exhibited at the New Orleans Cotton Exposition in 1884. Its rapid spread in the new environment soon made it a nuisance. Random samples of a compost manure of water hyacinth have shown a nitrogen percentage of 1.12 on a dry weight basis. Under optimum conditions the nitrogen percentage may range to 2.23 percent on a dry weight basis and the phosphoric oxide 0.86 to 8.0 percent. Based on the average weight of plants per square foot, half an hour after their removal from water, it was calculated that an acre of well-grown plants would weigh approximately 96 tons. The yield was assumed to range fom 4.3 to 6.7 tons of dry matter per month. It was postulated that as a true water plant, water hyacinth was especially suitable for effluent lakes with its major difficulty being its bulk and high percentage of water. Under suitable climatic conditions, one acre with cropping would remove 3,075 pounds of nitrogen per year, the discharge of 220 persons per annum.

Voigt, G. K. 1960.
Alteration of the Composition of Rainwater by Trees. American Midland Naturalist, Vol. 63, pp. 321–326.

The investigation was concerned with the nutrient content of rainwater, its modification by three forest cover types, and the net nutrient return to forest soils resulting from the addition of rainwater.

The area of study was located in southern Connecticut, a region which receives about 45 inches of precipitation per year. The water samples were collected from two storms, one in May and one in September.

The composition of rainwater collected in an open area in mg/l was as follows:

	May	September		May	September
Nitrogen (total)	0.05	0.07	Potassium	0.3	0.6
Phosphorus	.01	.01	Calcium	.6	.8

The differences in potassium and calcium content between May and September are probably related to the proximity of the study area to the highly industrial region of the east. This, together with differences in wind direction and storm movements, could cause great differences in the amount of air pollution.

Walton, G. 1951.
Survey of Literature Relating to Infant Methemoglobinemia Due to Nitrate-Contaminated Water. American Journal of Public Health, Vol. 14, No. 8, pp. 986–996.

Although methemoglobinemia may result from congenital heart diseases, or from the ingestion, inhalation, or absorption, or the medicinal administration, of any one of several drugs or chemicals, an important cause of cases in infants is the ingestion of water high in nitrate.

The permissible nitrate-nitrogen (NO_3-N) concentration in water which may cause infant methemoglobinemia when used in a feeding formula is dependent on the individual's susceptibility, the increase in nitrate-nitrogen concentration that is due to boiling the water, the quantity of boiled water consumed per day per unit weight of the infant, the duration of exposure to the high nitrate water, and possibly other factors.

Comly (1945) considered it inadvisable to use well water containing more than 10 or 20 mg/l nitrate-nitrogen (NO_3-N) in preparing an infant's feeding formula. No cases have been reported which were associated with water containing 10 mg/l nitrate nitrogen or less, and the nitrate nitrogen content was less than 20 mg/l for only 2.3 per cent of the cases for which data are available.

According to Sarles, et al. (1940), the principal sources of nitrogenous matter in the soil are the decomposition products of plants, animals and microorganisms; the liquid and solid wastes of animal metabolism; and fertilizers added to enrich the soil. The possibility of geological formations containing appreciable amounts of nitrates must also be considered. Since bacteria are essential in the production of nitrates from organic nitrogen, factors influencing their activity affect the nitrate content of the soil. Sarles, et al. (1940), note that nitrification takes place only when the soil contains buffering substances which neutralize the nitric acid and maintain a pH around 6.5 to 8.0; when aerobic conditions, such as result from plowing, cultivating, etc., are maintained; when soil contains only 50 per cent

of its water-holding capacity; when ammonia salts and other nutrient elements are present in the soil; and at temperatures above 50° and below 100° F.

Comly, H. H. 1945.
Cyanosis in Infants Caused by Nitrates in Well Water.
Journal American Medical Association, Vol. 129, pp. 112–116.

Sarles, W. B., Frazier, W. C., and McCarter, J. R. 1940.
Bacteriology (Rev. Ed.), Madison, Wis.: Kramer Business Service.

Webster, G. C. 1959.
Nitrogen Metabolism in Plants. Row, Peterson and Co., Evanston, Illinois, 152 pp.

The nitrogenous substances assimilated by plants can be divided into four major classes: organic nitrogen, ammonia nitrogen, nitrate nitrogen, and molecular nitrogen. Although a few plants (certain bacteria and algae) can assimilate all four forms of nitrogen, the great majority can utilize only nitrate, ammonia, and various forms of organic nitrogen as shown in the following table:

Utilization of various forms of nitrogen by plants

Organism	Organic nitrogen	Ammonia nitrogen	Nitrate nitrogen	Molecular nitrogen
Some fungi, some bacteria, and some species of *Euglena*	X			
Some fungi, some bacteria	X	X		
Most bacteria, fungi, algae and higher plants	X	X	X	
Some bacteria and blue-green algae	X	X	X	X

Weibel, S. R., R. J. Anderson, and R. L. Woodward. 1964.
Urban Land Runoff as a Factor in Stream Pollution. Journal Water Pollution Control Federation, Vol. 36, No. 7, pp. 914–924.

Stormwater runoff from a 27-acre residential and light commercial drainage basin with separate sewers in the Cincinnati, Ohio, area contained 2.5 and 8.9 pounds per acre per year PO_4 and total nitrogen-N, respectively. Based on a population density of 9 persons per acre and a flow of 100 gallons per capita per day, the comparative raw sanitary sewage would contain 27 and 81 pounds per acre per year PO_4 and total N, respectively. Phosphates in stormwater runoff constituted 9 percent of the phosphates in the calculated raw sanitary sewage and total nitrogen-N composed 11 percent of the total nitrogen in sewage.

Whipple, G. C., G. M. Fair, and M. C. Whipple. 1948.
The Microscopy of Drinking Water. John Wiley and Sons, New York, 586 pp.

Free ammonia indicates organic matter in a state of decay. Nitrates tend to increase in cold weather after the growing season, and free ammonia and nitrites decrease because of inhibited bacterial action. In the spring ammonia and nitrites usually increase in advance of growing plant life.

"Putrefaction and decay of dead organisms and waste materials give rise to ammonia compounds that are assimilated by some plant organisms; usually the nitrogen of the ammonia compounds is carried to nitrites and nitrates by oxidizing bacteria. The oxidized nitrogen becomes one of the chief foods of plants in building up protein. To a slight extent oxidation is sometimes reversed and nitrates are reduced to nitrogen that may be dissolved in the water or escape to the air, thus representing a loss. Plant protein becomes animal protein. Finally death of both plants and animals returns nitrogen to the process of putrefaction and decay. A short circuit in the cycle is the digestion of protein with elimination of urea, from which ammonia is derived without putrefaction."

Whitford, L. A. and R. C. Phillips. 1959.
Bound Phosphorus and Growth of Phytoplankton. Science, Vol. 129, No. 3354, pp. 961–962.

No correlation was found between phytoplankton pulses in four North Carolina ponds and variations in bound (total) phosphorus. It was concluded that the interaction of a complex of chemical and physical factors produces both seasonal fluctuations and sporadic blooms of phytoplankton.

Winks, W. R., A. K. Sutherland, and R. M. Salisbury. 1950.
Nitrite Poisoning in Pigs. Qd. J. Agric. Sci., Vol. 71, pp. 1–14; Water Pollution Abstracts, Vol. 25, No. 10, Abs. No. 1528.

Pigs fed with soups prepared with well water containing 1,740 to 2,970 mg/l sodium nitrate died from methemoglobinemia. Experiments showed that 0.09 grams of sodium nitrite per kg. of body weight was fatal to pigs and it was concluded that poisoning was due to nitrites derived from the nitrates.

Wurtz, A. G. 1962.
Some Problems Remaining in Algae Culturing. Algae and Man (D. F. Jackson, editor), Plenum Press, pp. 120–137 (1964).

In ponds, the introduction of phosphates into the water raises the pH of the mud, accelerating the reactions of decomposition in the mud, and liberating from the mud not only inorganic but also organic nitrogen.

Zicker, E. L., K. C. Berger and A. D. Hasler. 1956.
Phosphorus Release from Bog Lake Muds. Limnology and Oceanography, Vol. 1, No. 4, pp. 296–303.

In laboratory experiments the percentage, as well as the amount of phosphorus released to the water from radioactive superphosphate fertilizer placed at various depths below the mud surface in an undisturbed mud-water system was indicated to be very small. There was virtually no release of phosphorus from fertilizer placed at depths greater than one-fourth inch below the mud surface. There was a higher percentage of soluble phosphorus contained in the water samples taken near the mud surface than in water samples taken at greater distances above the mud surface. The radiophosphorus placed one-half inch below the mud surface showed only a very slight tendency to diffuse into the water, while the radiophosphorus placed at the one-inch depth did not diffuse into the water at all.

Zilversmit, D. B., C. Entenman, and M. C. Fishler. 1943.
On the Calculation of "Turnover Time" and "Turnover Rate" from Experiments Involving the Use of Labeling Agents. Journal of General Physiology, Vol. 26, No. 3, pp. 325–331.

The term "turnover" refers to the process of renewal of a given substance which may be accomplished by (1) the incorporation of labeled atoms into a substance, (2) the entering of a labeled substance into a tissue, or (3) a combination of the above two processes. The "turnover rate" of a substance in a tissue is the amount of the substance that is turned over by that tissue per unit of time. The "turnover time" of a substance in a tissue is the time required for the appearance or disappearance of an amount of that substance equal to the amount of that substance present in the tissue. If the rate of appearance of a substance in a tissue is "a" and the amount of that substance present in that tissue is "b," the turnover time is $\frac{b}{a}$.

U.S. GOVERNMENT PRINTING OFFICE:1965

Definitions and Equivalents

cfs=cubic feet per second; cfs×448.8=gallons per minute; cfs×5.4×10^6=pounds per day

g/l=grams per liter; g/l×1,000=parts per million

g/m^2=grams per square meter; g/m^2×8.922=pounds per acre

ha=hectare; ha×2.471=acres

kg=kilograms; kg×2.2=pounds

kg/ha=kilograms per hectare; kg/ha×0.8922=pounds per acre

metric tons×2,204=pounds

μg-at P/g=microgram atoms phosphorus per gram=31 parts per million phosphorus

μg-at P/l=microgram atoms phosphorus per liter=31 parts per billion phosphorus

μg/g=micrograms per gram=ppm

μg/l=micrograms per liter=ppb; μg/l×10^{-3}=parts per million

μg/m^2=micrograms per square meter; μg/m^2×8.92×10^6 =pounds per acre

mg/g=milligrams per gram; mg/g×10^3=ppm

micromoles P per 100 grams×0.31=parts per million

mg/l=milligrams per liter=parts per million

mg/m^3=milligrams per cubic meter; mg/m^3×0.00272 =pounds per acre-foot

mg/m^2=milligrams per square meter; mg/m^2×8,922 =pounds per acre

mg %=milligrams percent=milligrams in 100 grams=1 part in 100,000 parts wet weight; mg %×0.1=ppm

mgd=million gallons per day; mgd×1.547=cubic feet per second

ppb=parts per billion

ppm=parts per million

P_2O_5=phosphorus pentoxide; P_2O_5×0.436=P

PO_4=phosphate; PO_4×0.326=P

NO_3=nitrate; NO_3×0.226=N

Parts per million×cubic feet per second×5.4=pounds per day (gallons per minute×2.228×10^{-3}=cubic feet per second)

Parts per million×8.34×gallons per day×10^{-6}=pounds per day (gallons per minute×1,440=gallons per day)

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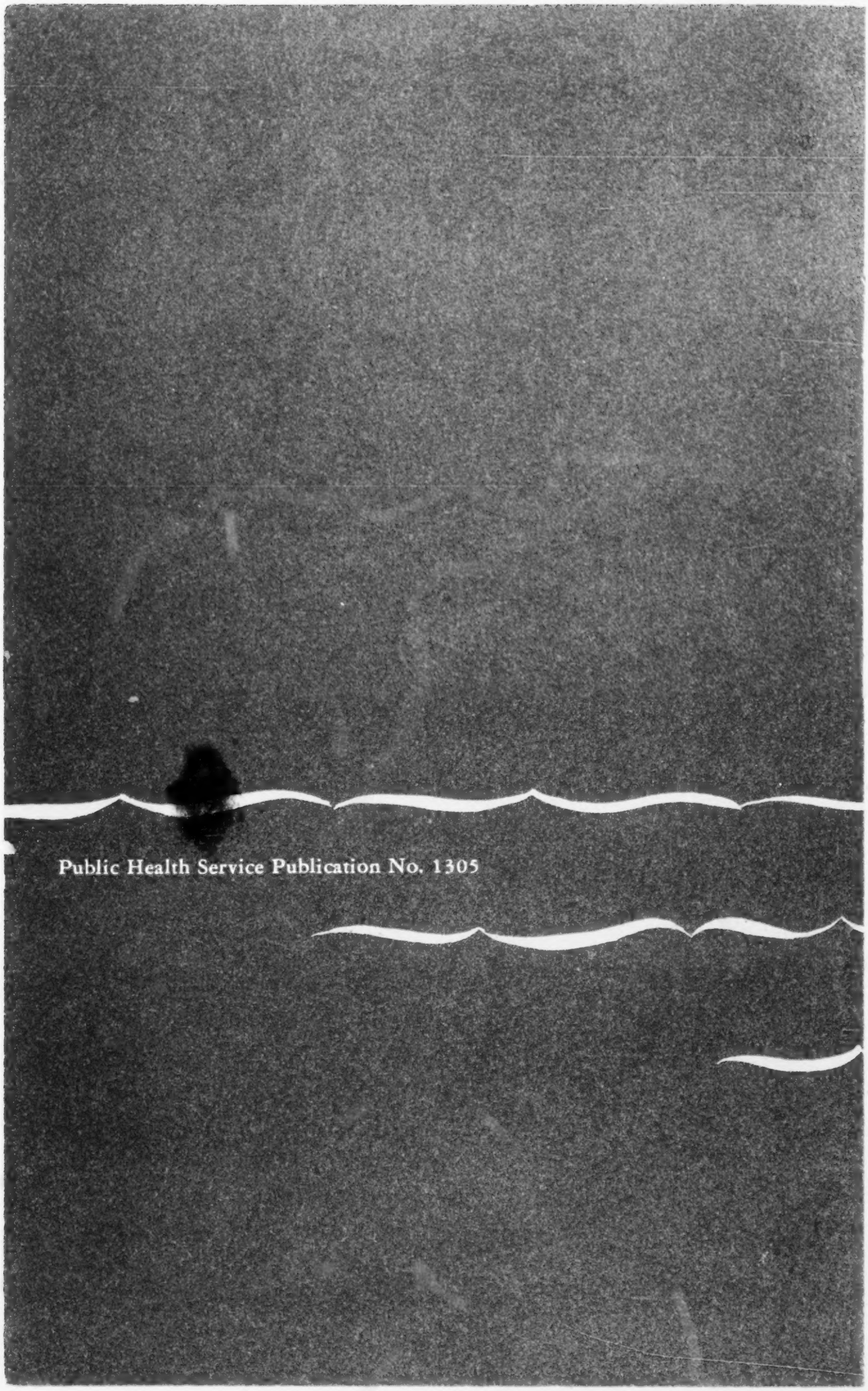

Public Health Service Publication No. 1305